Article

The Zero Energy Idea in District. Application of a Methodological Approach in the Case Study of Epinlieu (Mons)

Sesil Koutra[1], Claire Pagnoule[2], Nicolaos-Fivos Galatoulas[3], Ali Bagheri[3], Thomas Waroux[4], Vincent Becue[1] and Christos S. Ioakimidis[3,*]

[1] University of Mons, Faculty of Architecture and Urban Planning, ERA Chair Net-Zero Energy Efficiency on City Districts, NZED Unit, Research Institute for Energy; sesil.koutra@umons.ac.be; vincent.becue@umons.ac.be;
[2] University of Mons, Faculty of Architecture and Urban Planning; claire.pagnoule@student.umons.ac.be
[3] University of Mons, ERA Chair (*Holder) Net-Zero Energy Efficiency on City Districts, NZED Unit, Research Institute for Energy; nikolaos-foivos.galatoulas@umons.ac.be; ali.bagheri@umons.ac.be; christos.ioakeimidis@umons.ac.be;
[4] University of Mons, Faculty of Architecture and Urban Planning; thomas.waroux@umons.ac.be
* Correspondence: christos.ioakeimidis@umons.ac.be; Tel.: +32(0) 65374462

Abstract: Through history, particular attention has been paid of the study of the relationship between the energy use and the city structure. Improving energy efficiency in modern agglomerations is the most promising means to mitigate climate change and its impacts. In this current context of globalisation, European Union proposes initiatives and policy targets to rethink the urban development strategies towards the 'zero energy objectives'. Providing a methodological approach with a simulation district analysis, the present article summarizes how the 'zero energy' challenge is analyzed in an existing district (Epinlieu) to articulate the users' requirements in energy. This study contributes to the scientific discussion of the districts' urban structure and energy planning by establishing a linkage among the beneficial influence of the KPIs of the districts' form to increase their energy efficiency and its application in a real case study in Belgium.

Keywords: Case study; District; Energy; Structure; Zero

Nomenclature

EU	European Union
GHG (emissions)	Greenhouse gases (emissions)
NZED	Net Zero Energy District
U-ZED	Urban – Zero Energy District
KPIs	Key Performance Indicators
GDP	Gross Domestic Product
CERTU	Centre d'Etudes sur les Réseaux, les Transports, l'Urbanisme et les constructions publiques
ZEB	Zero Energy Building
NZEB	Net Zero Energy Building
EPBD	European Performance of Buildings Directive
GIS	Geographical Information Systems
HOMER	Hybrid Optimization Model for Electric Renewables
NPC	Net Present Cost

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 23 July 2019 doi:10.20944/preprints201907.0257.v1

1. Introduction

In the aftermath of the first two energy crises in 1973 and 1978, Europe intensified the effort to become gradually independent of fossil fuels [1]. The rapidly growing world energy use has already raised concerns over supply difficulties, exhaustion of energy resources, heavy environmental impacts of the climate change, etc. During the last two decades, primary energy has grown by over 40% and CO_2 emissions by 43% [2]. Over 60% of the global energy demand is consumed in contemporary cities by increasing the energy requirements [3]. Lhendup et al. [4] explain the importance of the energy demand and consumption as critical factors for the economic and sustainable development of modern cities [5].

A major part of the world's population lives in urban 'megapoles', where the economic, social and environmental processes affect the human societies, with major impacts. The implications of the urbanisation, both in terms of resources and living conditions (pollution, congestion, etc.) are numerous. Cities, as living organisms with dynamic and continuously changing processes at their systems, the energy demand is increasing and the available resources are getting exhausted generating considerable impacts ([6];.[7]).

Transitions of modern cities to 'mitigate' the disastrous impacts of the climate change require a combination of initiatives and policy targets in existing environments and create challenges [3]. Through a static interpretation of modern phenomena in urban development, planning 'smartly' demands allocative decisions to ensure the liveability of modern cities.

In such a context, European Union introduces directives pertaining to the energy performance of buildings and targets to identify the demand energy management as a significant tool for the optimisation of the user demand ([8]-[9]). Already in 2008, EU introduced its policy targets regarding the 2020 climate and energy objectives: 20% reduction in GHG emissions comparing to 90s levels by increasing the share of EU energy performance derived from renewable resources at 20% with a parallel improvement of 20% in EU's energy efficiency. Following this strategy, the 'chapter of energy' has been of high priority for the future urbanization strategies [10].

1.2 Objectives of the research

In particular, the objectives of this research are:

- To accentuate key challenges in districts by pinpointing the criteria of the zero energy district planning.
- To expand the zero energy concept from buildings to larger territorial scales (districts) and its application in real case studies.
- To simulate the analysis and modelling of NZED models testing various indicators and interconnections among them.
- To apply a methodological approach in a real case study and consider the perspectives for its future transition towards the zero energy objectives.

1.3 Structure of the paper

The paper is structured accordingly. Section 1 introduces the problem, the objectives of the research and the paper's structure. Section 2 highlights the importance of the urban structure for the reduction of the energy demand/consumption of its users; Section 3 presents the main issues of the methodological approach (U-ZED). Section 4 provides the main findings and results of the U-ZED methodology application in the district of Epinlieu in Belgium. Section 5 summarizes the major highlights of the current work, while Section 6 discusses the perspectives for future work and continuity of the study.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 23 July 2019 doi:10.20944/preprints201907.0257.v1

2. Energy and urban structure. A state-of-the-art analysis

2.1 Literature review and previous works

Cities play a central role in driving global energy demand. Girarbet [1] highlights the 'energy management' as a priority issue in future urban development of modern cities. Große et al. [2] cite the interrelation among the urban structure and the energy as a key perception in climate policies. Indeed, for decades, the urban development in city districts has been influenced by initiatives related to renewable resources to enhance the energy efficiency in buildings and reduce the energy requirements.

The connection among the urban structure and the energy consumption in cities has been investigated by scholars and studies for more than three decades and is being increasingly incorporated in policy-oriented documents from the EU and other institutions [2]. Owens [3], Salat [4] and Ewing and Rong [5] have analyzed the influence of the density, the architecture and the urban structure in energy consumption. One of the first in-depth studies to investigate urban structure and its implications for urban energy supply and consumption was conducted by S. Owens [3] with the identification of the energy-efficient attributes in its spatial structure (Fig. 1). Owens argues that the factors of the energy inventory (resources); the shape and structure of the agglomeration; etc. determine the energy requirements and the final consumption. Owens identifies the energy efficient attributes of the spatial structure concluding that the most influential are: the compactness; the integration of land uses; the number of dwellings; etc. and describes the 'linear grid structure' as the basic type of energy-efficient spatial structure. Ewing and Rong [5] conclude that the amount of delivered energy use for domestic uses (mainly heating and cooling) are related to the physical form and attributes of the residential dwellings.

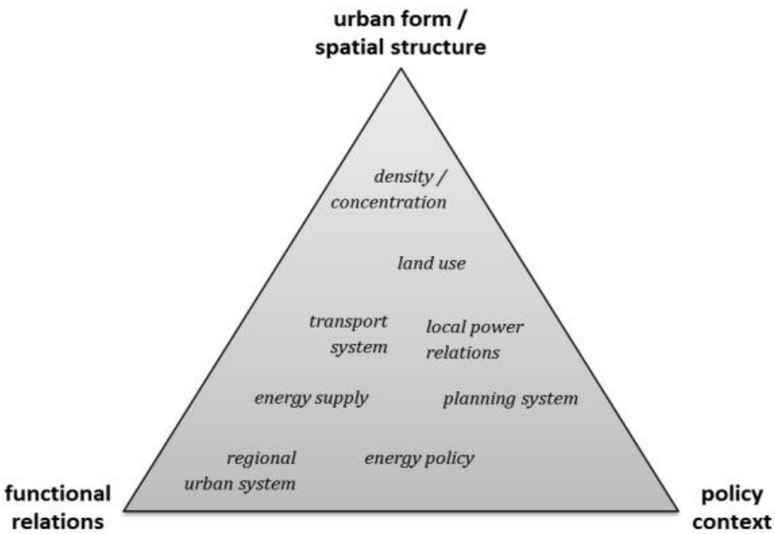

Figure 1. Urban form/spatial structure, functional relations and policy context as interrelated dimensions

Indeed, Owens [11] further attempts to quantify the magnitude of the KPIs of the urban structure (Fig. 2) and their potential impacts and implications on energy consumption.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 23 July 2019 doi:10.20944/preprints201907.0257.v1

Structural Variable	Scale
Settlement pattern Communication network between settlements Size of settlement Shape of settlement Communication network within settlement	Region
Size of settlement Shape of settlement Communication network within settlement Density Interspersion of land uses Degree of centralisation of facilities	Settlement
Density Interspersion of land uses Degree of centralisation of facilities Layout Orientation	Orientation
Layout Orientation Siting Design	Building

Figure 2. Urban structure variables affecting energy at diverse urban scales

Newman and Kenworthy [10] explain how the geographical factors influence the energy consumption. 'Gasoline Consumption and Cities: A Comparison of U.S. Cities with a Global Survey (1989) [10] is one of the most influential planning work of all time, where Newman and Kenworthy suggest that in world cities (actually metropolitan areas), per capita fuel use is inversely related to GDP. The relationship follows an exponential function (Fig. 3).

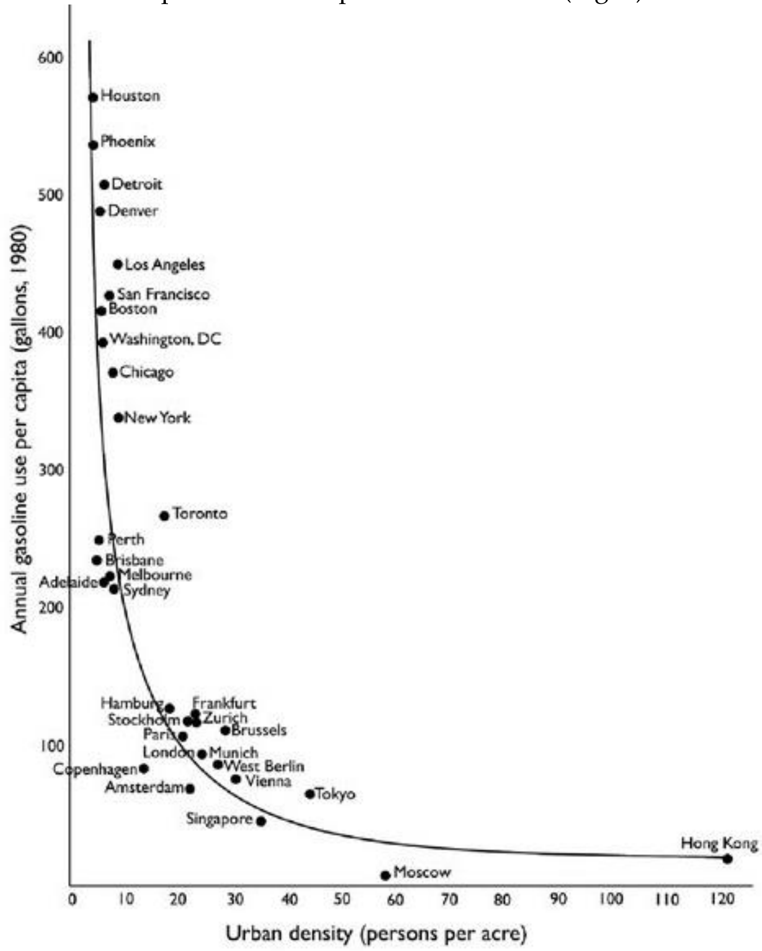

Figure 3. Gasoline use per capita versus population density, 1980

Papa et al. [6] conclude that it is imperative to consider the interrelations among the diverse components. Urquizo et al. [7] at their works explain why we search for energy use in agglomerations considering the cities as a significant proportion of the world's energy consumption. Baker and

Steemers [8] consider the overall impacts of the urban form on building energy. Miller [9] referring to 'building morphology' reflects the size and the shape of building, including the characteristics of its envelope [10]. Among the most interesting attributes to influence the building energy consumption is the: compactness [10] and the building density [9]. The 'compactness' has a predominant effect on reducing the heat transfer, as more compact building shapes enclose more building volume with less surface areas.

On the other hand, the 'building density' and 'energy' represent various illustrations across the academic manuscripts. Steemers [11] states a potential of 50% of reduction in heating requirements by increasing the building density. Ewing and Rong [5] conclude that households living in low-density, single family homes, etc. consume more than 50% of energy for space heating and more than 20% for cooling comparing to multi-family or terraced houses. Nonetheless, the relationships among the criteria of 'compactness' and 'building density' reduce generally the heat loss without guaranteeing the reduction in building energy consumption, as their 'interpretation' is complicated between the diverse land-uses and functions [9].

Generally speaking, literature review investigates energy issues at a district scale by focusing on the impacts of urban structure on energy consumption in buildings [8]. Marique et al. [12] analyse the impact of the territorial pattern on energy consumption in the Walloon Region in relation with the residential built environment and home-to-work commuting in terms of household location, employment and mobility infrastructure.

2.2 The role of the urban structure in the district energy management

The objective of a typo-morphological frame is the analysis of the physical and spatial structures and their transformation as well. This analysis is a critical evaluation for the urban 'organisms' and their future [13]. Seto [14] quotes two great transformations occurred in the last decades relate to the cities' structure:

'… one, where the scales, rates and kinds of environmental changes have been fundamentally altered as humanity passed through an era of rapid population growth…' (pp. 170)

'…Humanity crossed a milestone in 2008, when the global urban population exceeded the rural population for the first time in history….' (pp. 170)

Anderson et al. [15] define the 'urban structure' as 'the spatial configuration of fixed elements within a metropolitan area, meaning the spatial patterns of the land use, spatial design of transport and infrastructure facilities, etc. Generally, the urban structure is the combination of space, time and activities' [16]. Broadly, the urban morphology is referred to as 'the form of human settlements, reflected in the various layouts and patterns of the urban fabric, which is transforming the structure in cities continuously' [17]. Nevertheless, the urban morphology and form are still misunderstood in the scientific literature [18]. In fact, the urban morphology reflects the transformation and the transition of the urban structures focusing on the spatial dimension and building typologies [19]. As an example, Salat [4] stated the building shape factor and its volume as functions of the urban morphology, while Sarralde and Steemers [20] present the subsequent morphologies: vertical, horizontal distribution, land use, building geometry, density.

The parts that compile the territory and it is the study of the urban structure within its historical development by its constructive elements [21]. CERTU frames the urban 'morphology' as a resultant of historical, political, cultural and mainly architectural modifications and a consequence of a spontaneous evolution by the public or private authorities [22]. Levy [23] proposes that the morphology is a polymorphic notion of various aspect. The reduction in consumption is related to the fact that the morphology affects also the microclimate of the urban area through shape factors and the percentage of solar radiation reaching the façade [24] (Fig. 4):

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 23 July 2019 doi:10.20944/preprints201907.0257.v1

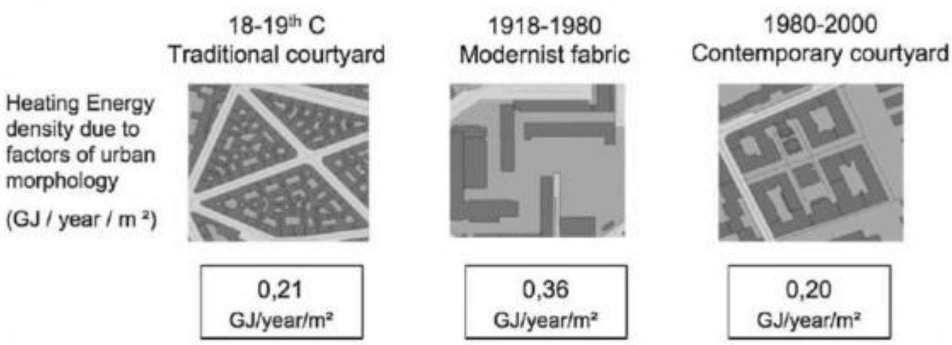

Figure 4. Effect of urban morphology on the energy need of building stock in Paris

The discussion around the urban structure and its relation with sustainability has been framed by a duality between the compact and disperse urban structure, and its relation with multiple domains (i.e. mobility, economy, social cohesion, etc.) (Fig. 5) [23].

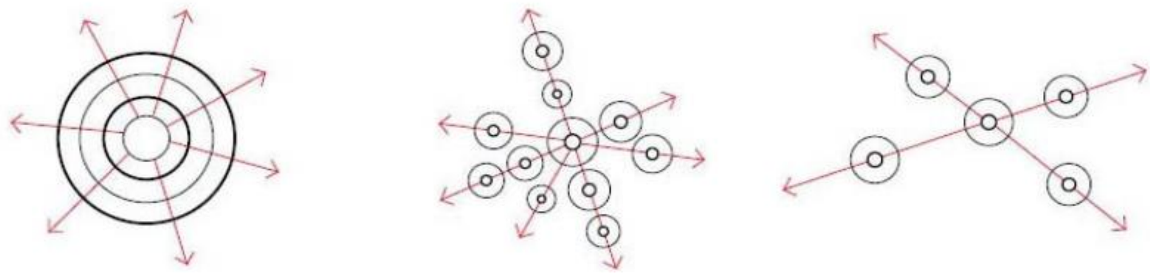

Figure 5. Various perspectives on a 'sustainable' urban system: compact centres, agglomerations

To understand and compare the diverse urban typologies for an urban project the London School of Economics [25] analyzed Berlin, Istanbul, London and Paris by identifying 25 urban configurations through five (5) structures to evaluate the density, the compactness and the building attributes (Fig. 6). Fig. 6 provides the typical analytical metrics of qualitative physical indexes of the urban structures. Fig. 6a describes the problematic of 'complexity' in structures and the possible shape irregularities; Fig. 6b the 'centrality' and the degree to which the urban development is close to the Central Business District; Fig. 6c measures not only the 'shape' but also the fragmentation of the overall structure and Fig. 6d mentions the indicator of 'porosity'; meaning the ratio of open space compared to the total urban area.

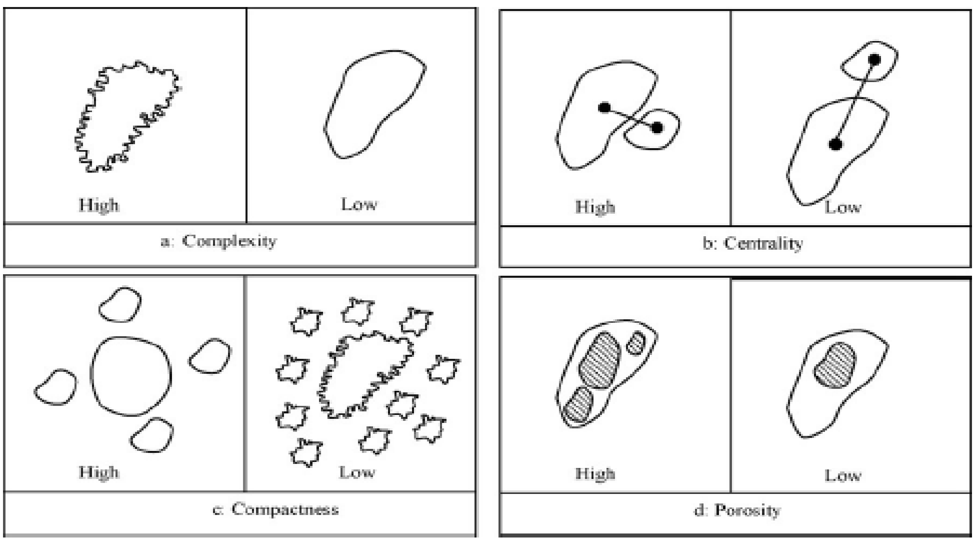

Figure 6. Typical analysis of diverse urban typologies for London School of Economics

The pattern of energy consumption individually is often unpredictable and its fluctuations along the day unrevealed as the behavior of a single household seem to be random due to the inconsistent

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 23 July 2019 doi:10.20944/preprints201907.0257.v1

individual use of its appliances for short periods as explains Borlin [24] at his studies. On the other hand, when we are talking about an urban agglomeration more than an individual household are accumulated, thus, the patterns of energy consumption are more defined (Fig. 7):

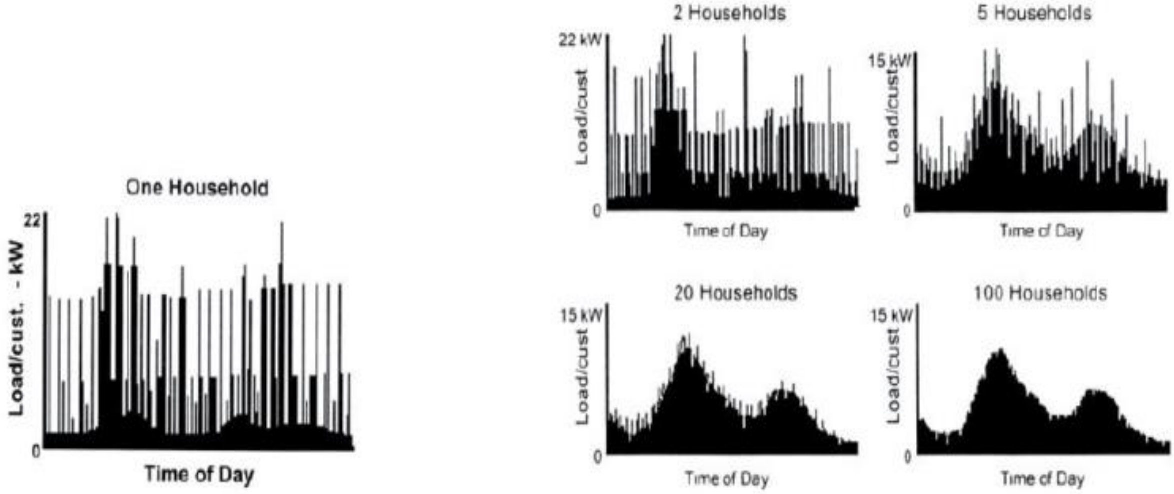

Figure 7. Consumption pattern with the increasing number of households

3. Methodological approach

3.1 The concept of 'zero energy'

In literature and academic manuscripts, the 'zero energy' objective is mostly considered on building scale. Although, existing definitions are commonly articulated around an energy balance. Broadly, the 'Zero Energy Building' (ZEB) is presented as 'a general concept including autonomous buildings not connected to energy grids' [26]. The term 'Net-Zero Energy Building' (NZEB) underlines 'the fact that there is a balance between the energy taken from and supplied back to the grids over a period of time (nominally a year)' [26].

Undoubtedly, the deployment of the NZEBs attracts the intention of scholars and research community because of its mandatory performance from 2020 onwards [27]. Significant work has been done on the definitions of the concept and its 'translation' to buildings on the development of methodologies in design; energy modelling etc. ([26], [28], [29]). This large range of interpretations and challenges to face for the zero energy transition and the achievement of its objectives at buildings also lead to strategies, in which the urban scale is included (for instance the mobility). The concept assesses the application of the zero energy concept in districts and it is essentially related to the reduction of the energy demand to almost 'zero' coupled to the energy supply from renewable resources [27].

A first proposal to define the zero energy concept in communities found in Carlislie et. al. [37] works arguing 'a NZED reduces the requirements in energy through efficiency gains, such as the balance of energy for vehicles, thermal and electrical energy within the renewable local resources'. Marique et al. [12] adapt this definition to consider the energy produced in a district as the sum of the needs for every single building and the mobility of its users. EPBD Directive [30] assumes that a 'Nearly Zero Energy District is a delimited part of a city having high energy performance with the zero or very low amount of energy covered to a great extent by local production'. In this context, Amaral et al. [31] consider that the NZEDs is not a sum of NZEBs but a group of buildings with different consumptions, whose overall balance reach almost the zero.

3.2 The role of the district

Micrograph and the constructive element of the city [29], the district identifies the patterns of energy consumption and provides concrete 'planning' solutions towards the 'sustainability' and strategic urban planning. The district is regarded as an appropriate scale incorporating the components to facilitate the application of optimisation tools and improve the energy performance by minimising the requirements and the cost for infrastructure [30].

Jenks and Dempsey [31] define the 'district' as the 'combination of 'geographical boundaries or cultural attributes' of the users among its users or facilities for leisure, health, etc.'. Barton et al. [32] focus on spatial aspects considering the 'district' as the area of distinctive identity. Amaral et al. [31] refer to the 'district' as 'a representation of new interests and an intermediate scale in urban strategies and studies given the intermediation among the buildings and the surroundings going beyond the limits of the single buildings and simultaneously capable to address tangible and 'smart' solutions'.

Another advantage of a district zero energy approach is the diversity in load to supplementary energy savings by creating opportunities for heat recovery. Many strategies used in districts to achieve zero energy also increase the resiliency of the district. Last, the district might be at a more advantageous scale than individual buildings for managing aggregate loads and interactions with the larger power grid [32].

For this study, the district is understood as an 'urban block' and a complicated system with diverse key parameters of its 'internal' and 'external' environment including mobility, human factor, exchange of services among the other districts in a city, etc. (Fig. 8). Fig. 8 introduces the 'definition' and the understanding of a district for the application of the U-ZED methodology. In particular, the district is defined as a 'system', in which the interrelations among its diverse elements are existing in a dynamic process (for instance the mobility issues of the users) as a continuous process of energy consumption and CO_2 emissions. Each district is a 'micrograph' and an 'individual' component of a

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 23 July 2019 doi:10.20944/preprints201907.0257.v1

city and a complex system with interchanges in services; infrastructure; etc. with the other districts of the same city (x2, x3, etc.). Fig.8 provides a representation of this process as a particular element towards the understanding of the applicability of the zero energy concept in larger scales. The systemic approach facilitates the comprehension of the idea in terms of 'inputs' and 'outputs' and the balance among them annually.

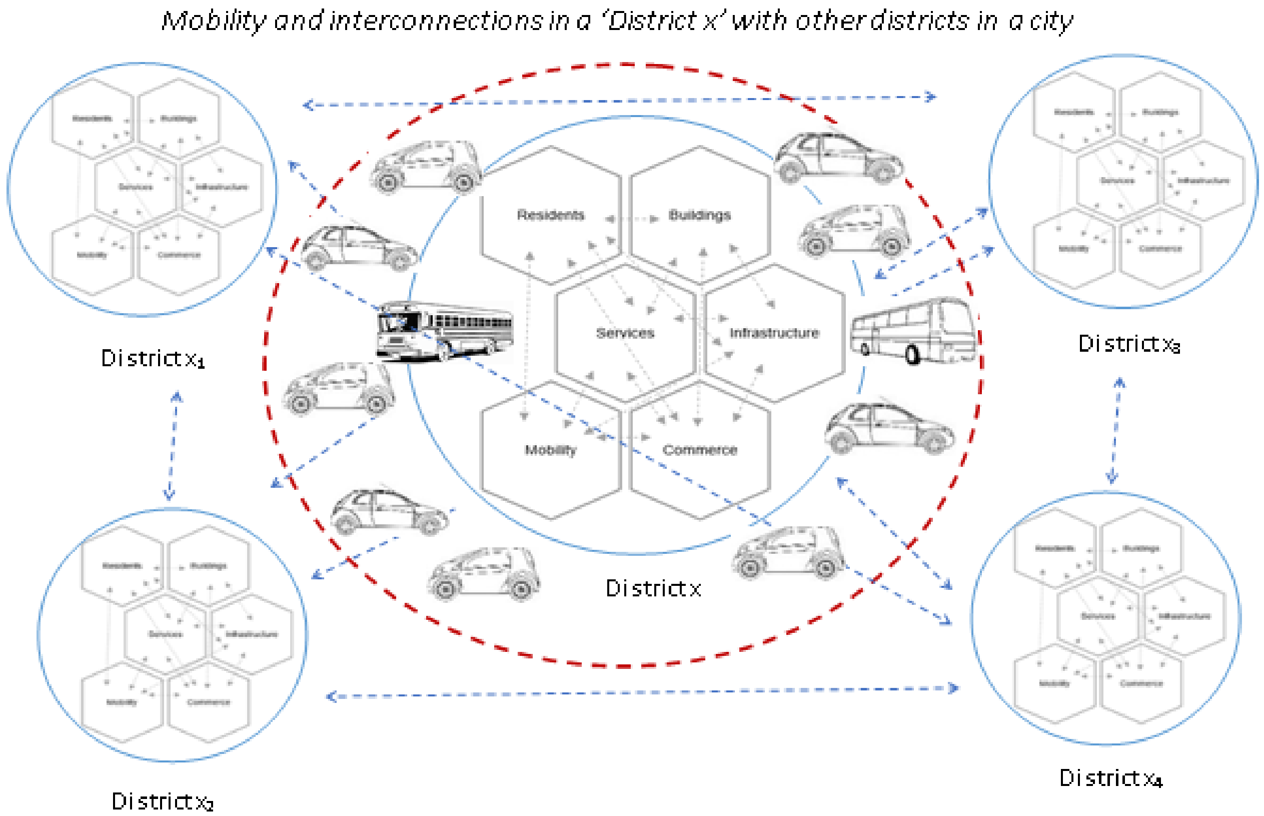

Figure 8. The understanding of the 'district' in the U-ZED methodological approach

3.3 Description of the methodology and steps

3.3.1 Development of a theoretical model

U-ZED is an introduced methodological approach defined in a multi-criterion context and a decision strategy towards the urban scheduling/programming of a district within the zero energy concept. The methodology is deployed in several phases. Each phase ensures an effective dialogue among all the city stakeholders and considers ways to strengthen confidence in the decision-making process of the zero energy planning (Fig. 9).

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 23 July 2019 doi:10.20944/preprints201907.0257.v1

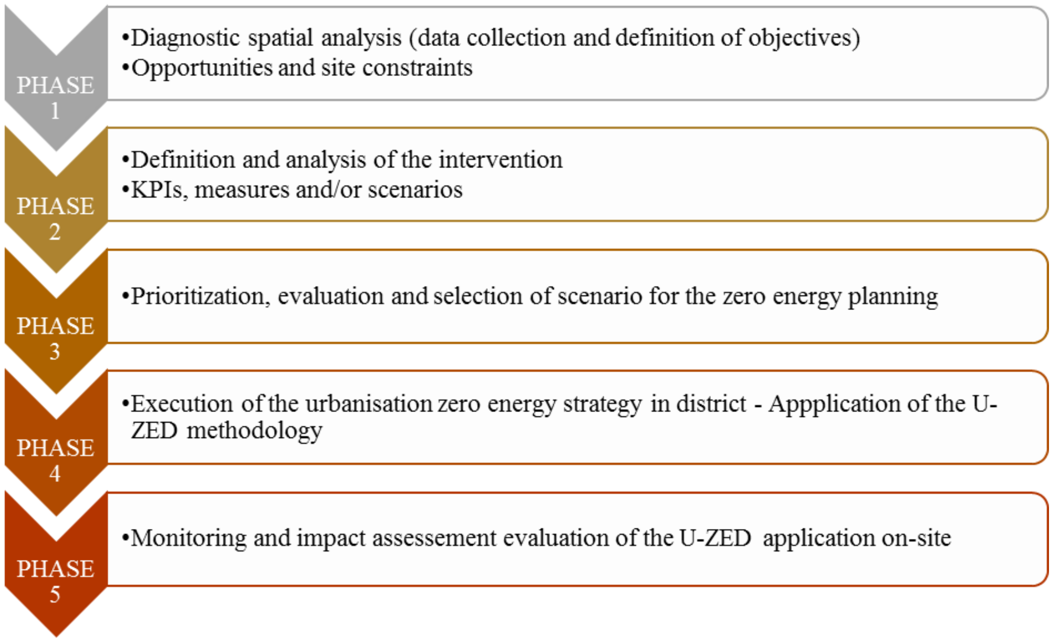

Figure 9. The U-ZED Approach in phases

In this current context, U-ZED proposes a simple brief of exploring the concept of increasing the energy efficiency and autarky in districts through a continuous strategy from the early conception of the urban/architectural project within a smart energy management contributing to the decrease of energy requirements of its urban and built environment. The general idea of the methodology proposed is illustrated in Fig. 10:

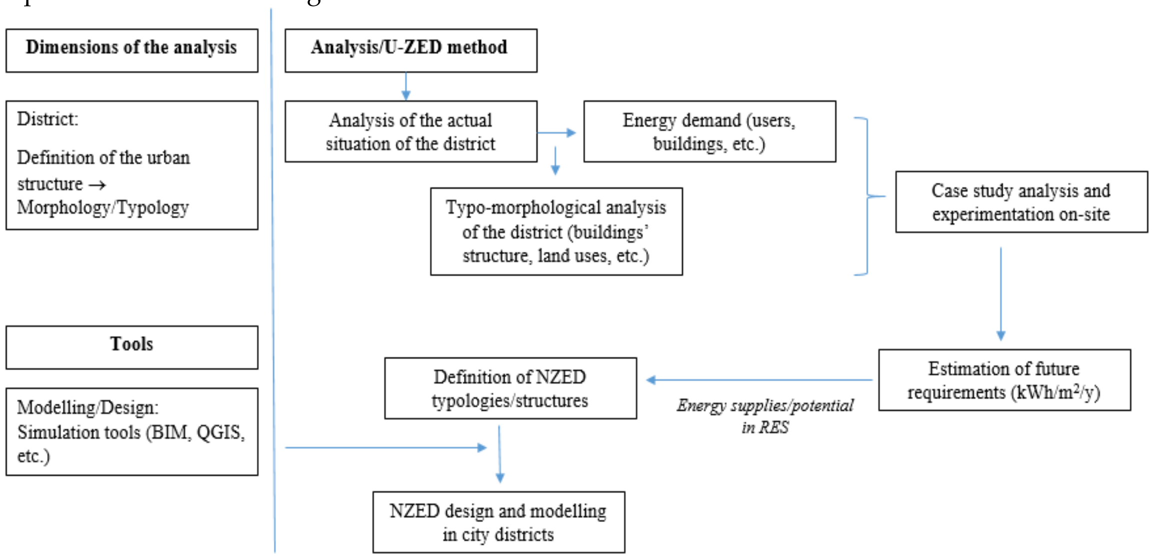

Figure 10. General description of the methodology

U-ZED approach 'engages' the districts from the conception to zero energy attributes regarding their urban and built environment and evaluates the existing districts as NZEDs or 'smart grounds'. The objective of the U-ZED approach is to develop a comprehensive local planning process, in which the challenge of the zero energy balance (Energy Demand ⊚ Energy Offer/Supply) is shifted from 'individual buildings' to larger scales (i.e. districts). In an urbanised environment, the 'need' for 'smart grounds' (NZEDs) is emerging when considering how spatial patterns, landscape, economic and social context rethinking in a new energy frame. In this vein, U-ZED considers the districts as a system, in which opportunities for the use of alternative resources (natural, etc.) are used in a local production to balance the demand of its users. The methodology adopted to develop the theoretical and practical frame of the approach consists of two phases (Fig. 11):

 doi:10.20944/preprints201907.0257.v1

A. Theoretical approach: description and the diagnostic phase of the problem taking into account the existing concepts. For the U-ZED approach, the 'problem' describes the 'optimal typo-morphological definition of the district with the zero energy attributes'. The phase concerns a systemic literature review addressing the domains of scientific knowledge, for instance:
   - Renewable energy: including the study and systematisation of planning factors being currently implemented in urban areas
   - Energy efficiency: exploring the promotion of energy efficiency in a widen perspective from retrofitting old buildings and renovating with new design patterns.
   - Spatial planning process: considering the history of planning practice and systematising the objectives of zero energy.

B. Experimental approach: validation of the criteria on site and experimentation of the approach in real case studies. Assessing the current situation of the district is the initial phase of the experimentation approach of the case study application. Thus, we analyze the potentialities in regards to energy, enhancement of mild mobility, etc., the connection of the existing urban tissue of the city in accordance with the objectives of the city planning, as a whole.

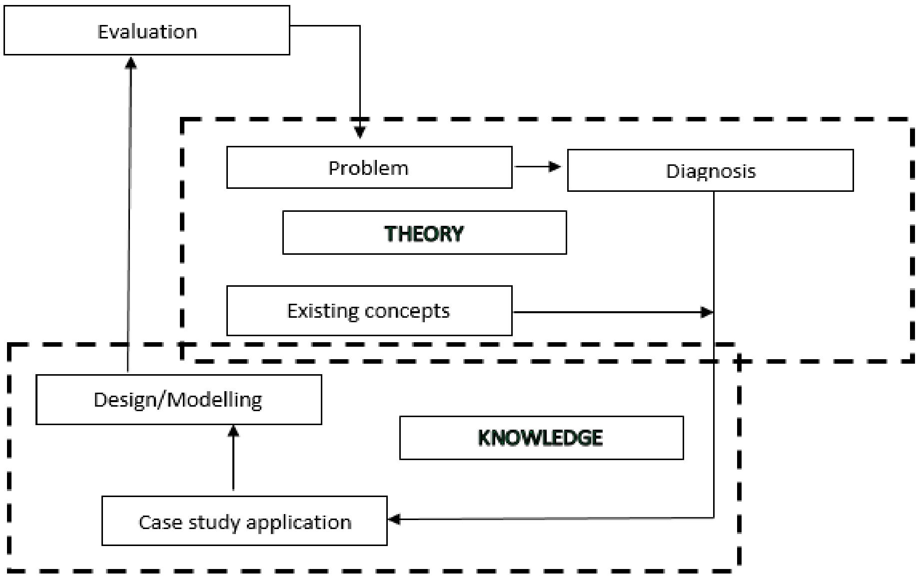

Figure 11. U-ZED concept

In reality, the U-ZED approach focuses its interest in the urban programming and conception of the district and its application from the early beginning of the project conception within the zero energy objective. The territorial diagnosis; the constraints and the potentialities; the current situation of the geographical site but also the analysis of the energy requirements are the preliminary steps of the U-ZED approach (Fig. 12):

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 23 July 2019 doi:10.20944/preprints201907.0257.v1

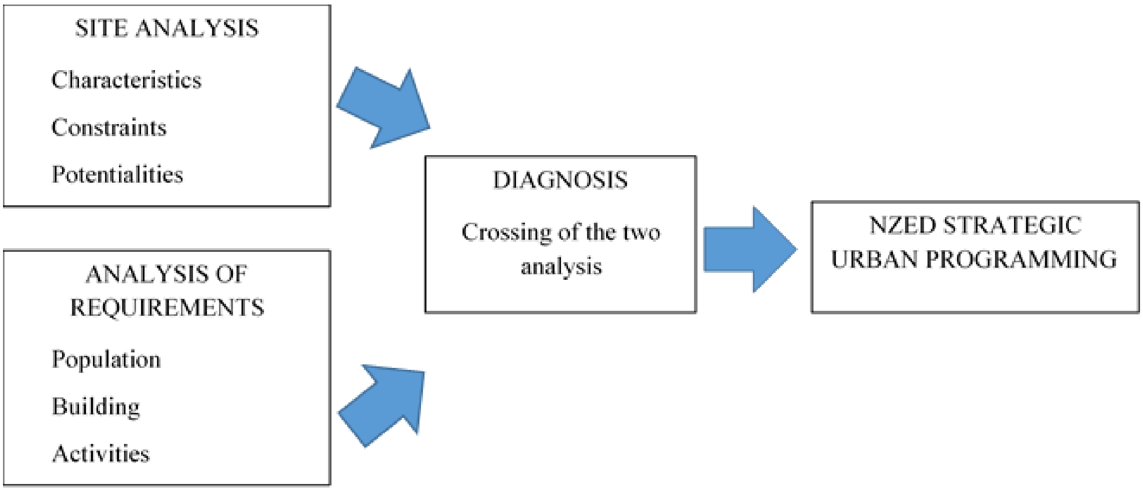

Figure 12. Diagnosis of the U-ZED approach

The approach is developed at the time being in a theoretical frame, projected to be evolved in solutions that are more tangible, and technical results with simulations in demonstration city districts' projects to validate the theoretical findings. Below, we provide a comparative table of the existing studies of the international scientific review to explain originality and innovative actions that our approach provides (Table 1).

Table 1. Methods & tools in literature to support studies of district and U-ZED novelty (adapted by [36])

Topic/field	Objectives	Methods/tools	Scale	Reference
NZED/ NZEB	Definition proposal for NZED	Hierarchical and qualitative approach	District	[33]
	Assessment of extending NZEB concept to district scale	Dynamic simulations	District	[34]
	Assessment of alternative scenarios for NZEDs' construction	Multi-criteria decision analysis	District	[35]
	Optimization of energy systems design towards NZED	Genetic algorithm	District	[36]
Sustainability assessment tools	Analysis of existing sustainability assessment tools	Comparative analysis and data	District	[37]
	Analysis of existing sustainability assessment tools	Comparative analysis and data	Urban	[38]
	Analysis of existing sustainability assessment tools	Top-down and bottom-up models	District	[39]
U-ZED	Development of a holistic theoretical methodological approach at the conception phase with a zero energy context	Parametrical concept of the NZED with the use of GIS tool	District	[40]

The three concepts of 'location', 'typology' and 'morphology' 'co-exist' in the understanding of the U-ZED methodology. For the better comprehension of the U-ZED approach we focus on the idea of the 'typology' and more precisely on the structure of its 'built environment' in an effort not to neglect interesting and important key issues that will influence the achievement of the zero energy objectives on site (Fig. 13). Fig. 13 recapitulates the main problematic of the feasibility in zero energy concept in districts; therefore the question of 'location' and the site opportunities and constraints (in regards to the energy offer and the actual inventory). Another important question is the identification of the building 'types' and the land uses of a NZED, as well as other criteria (density; mixing; population; etc.), which will define the energy requirements of the users.

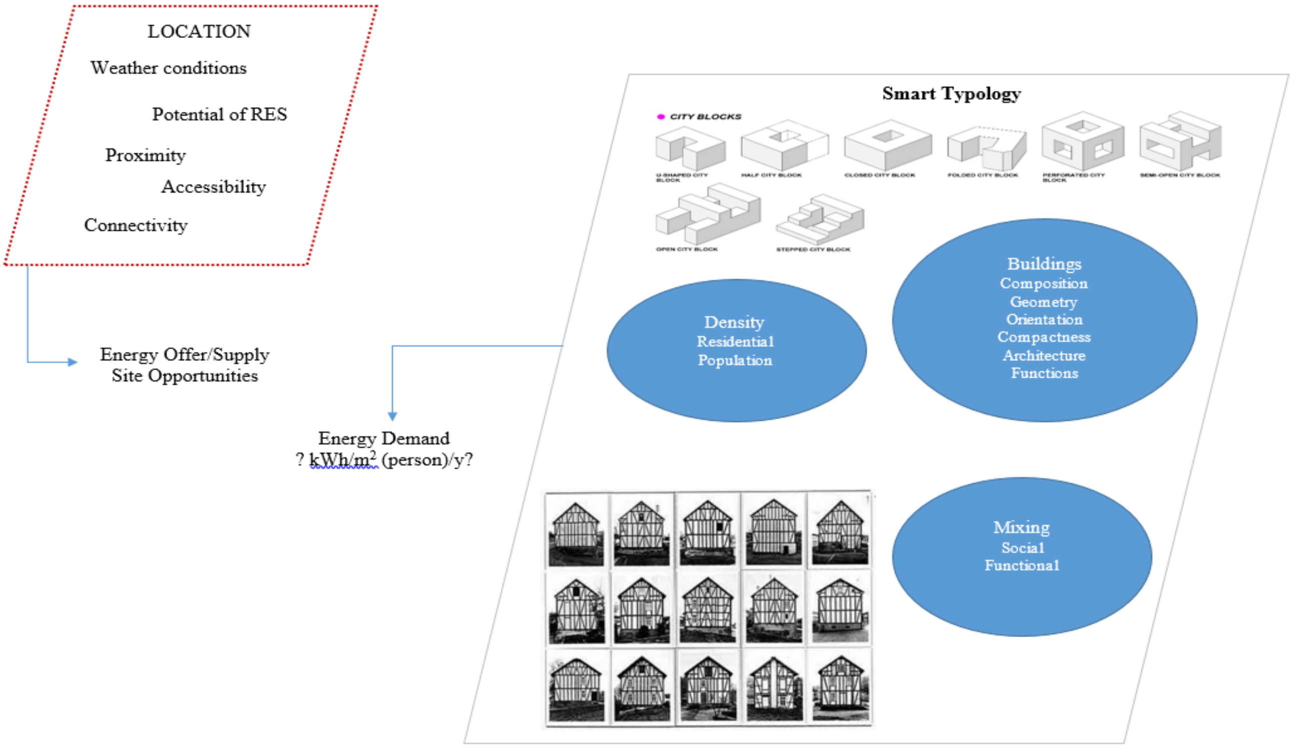

Figure 13. Criteria identification for NZEDs among the axis of ‘location’ and ‘typology’

In this context, the U-ZED approach studies the possibility of developing a strategic future planning and targets to:

1 The realisation of a ‘state of place’/description of the actual situation in terms of energy requirements in districts (kWh) by its buildings and users. The first step is the determination of the energy requirements ‘on-site’. To do so, there are many methods to obtain an approximation more realistic, for instance:
   - Real data use: this method is the more accurate considering the real quantities of energy consumed.
   - Approximation method based on the building typology
   - Approximation method based on the typologies as a whole: this method is the most approximate but simultaneously the rapidest one.

2 The policy targets and measurements for urbanisation strategies for zero energy concept in districts. The second step of the U-ZED approach is the development of scenarios to estimate the future energy requirements of the studied districts and assess the future needs of buildings and users in energy consumption related to the existing sources and supplies. As far as possible, this analysis considers also the evolution in population and the new constructed infrastructure or residential dwellings according to the users’ needs at the time being and in the future (Fig. 14).

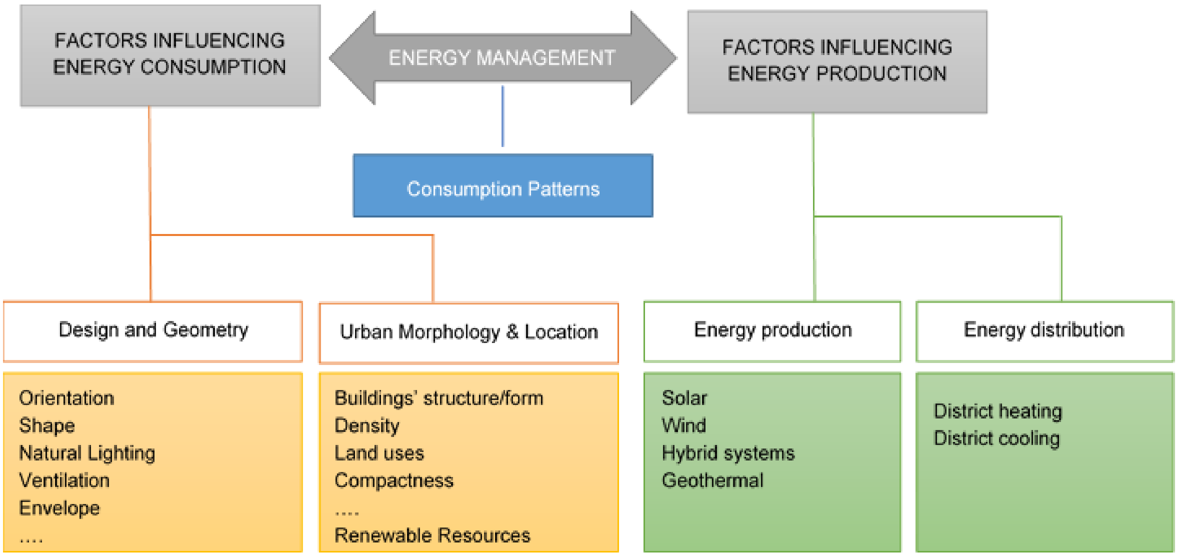

Figure 14. Overall of the key parameters and criteria influencing the zero energy concept in districts

3.4 Key Performance Indicators

The origin of KPIs is in business administration with the aim to provide tools for measurements in business fields. In reality, they are quantifiable metrics reflecting the performance of achieving wider goals and help the implementation of different strategies (in our case the zero energy planning in districts). KPIs are always tied to a goal, a target or an objective [41].

3.4.1 Evaluating the feasibility of zero energy concept in districts: The systemic approach

The measurement of the 'urban sustainability' is encouraged by the mechanism of a 'system' to describe the interrelationships of its variables (Fig. 15) [42].

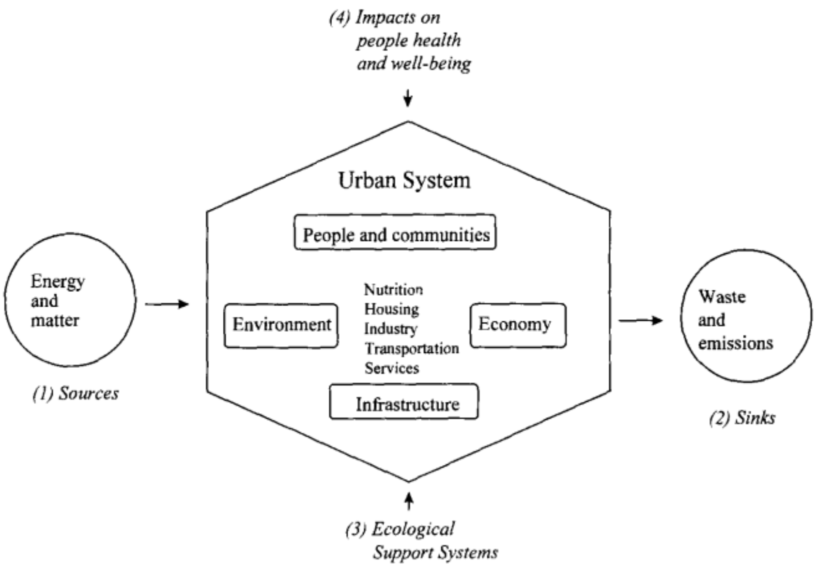

Figure 15. The district as a 'system'

3.4.2 Key Performance Indicators in U-ZED approach

Mitchell [10] underlines eight (8) KPIs for building energy consumption including: building consumption, users' activities, urban structure, etc. comparing to the works of Salat et al. [43] and Ratti et al. [44] (Table 2):

Table 2. Factors influencing building energy consumption

Mitchell [10]	Salat et al. [43]	Ratti et al. [44]

Urban geometry Building morphology Thermal performance of materials Efficiency of internal systems Occupants' activities & behavior Internal and external temperatures	Urban structure Building performance Equipment and system efficiency Users'/Occupants' behavior Type of energy use	Urban geometry Building design [8] Systems' efficiency Occupants' behavior

One of the most important topics of reviewing the indicators of NZEDs is to contribute to an accurate evaluation of the overall district energy demand. An indicator is a numerical value helping to quantify and simplify phenomena based on quantitative measurements or statics.

At the urban scale, the buildings' performance has been mainly associated to the availability of solar gain and natural lighting ([20], [45]). Assuming that the districts' energy consumption goes beyond the individual buildings, the energy consumed in public spaces should be considered as well in the overall energy balance. There are few approaches and scientific studies to a district scale in literature. Sanaieian et al. [46] highlighted the difficulties in studying the impacts of the surroundings on the performance of urban blocks as they emphasize on the complexity of including all the conflicting aspects simultaneously. For this study, we consider as key aspects for the energy performance of the NZEDs the: site opportunities and attributes, the typo-morphology of the built environment, the amenities and the parameters of the eco-cycle, as presented on Table 3 below.

Table 3. Key Performance Indicators in NZEDs'

KPIs	Criterion(a)	Description	U-ZED Approach	References
Site opportunities	Location Site topography	Choice of geographical site with a potential on energy resources Proximity to city centre Accessibility by mild means of transport	Climate conditions Distance from city centre: 3-5km Distance between the 'stops': 200-500m	[47]–[54] [47];[48];[49];[50] [51];[52];[53];[54][55]
	Mobility	Offer in mild means of transport	1.500m from IC/IR or less than 1.000m from a local railway station	[56]
		Parking	0.2-0.5 places per dwelling 500 places of parking in proximity to stations of means of transport	[56];[57];[58]
Resources	Natural resources	Production on-site	Local production by local resources at least 20%	[56]
Site attributes	Surface	Number of ha	Three district type proposed: 'Small' surfaces 'Medium' surfaces 'Large' surfaces	[59];[60];[51];[61]
	Population	Number of residents	≤5.000 inhabitants	[62];[59];[49];[48] ;[63]; [64]
Typology/ Morphology	Dwellings	Number of dwellings	500 - 2000	[59];[65];[48]
	Compactness	A dwelling is considered to be semi-detached if at least 80% of the area of two of its walls is in contact with a heated area	50% terraced 30% terraced	[59];[65];[48]
	Density	Dwellings/ha	≥30dwel/ha (poles) ≥40dwel/ha (suburban)	[66];[67];[59];[62];[63]
	Orientation (angle)	South-East and South-West orientation: identified as the most advantageous for	50% of the windows to the south 20% of the windows to east and west 10% of the windows to north Form 'L'	[68];[61]

 doi:10.20944/preprints201907.0257.v1

KPIs	Criterion(a)	Description	U-ZED Approach	References
		energy saving and reducing consumption		
	Functional and Social Mixing	Mixed use land uses in a NZED to ensure a social mixing in the districts/The minimum number of equipment in the NZED	15 equipement in a perimeter of 1000m 300m of a commercial centre in proximity 300m of a primary school in proximity 500m of an activity center in proximity	[56];[68]
	Social Mixing	Number of social dwellings/surface (ha)	15% in social dwellings 10% of district's dwellings accessible to 'middle' revenues	[69];[70];[56]
	Mixing in Dwellings	Variety of dwellings/land uses in NZEDs	10% studios and/or dwellings of 'one room' 10% of dwellings of 'two rooms' 10% of 'three rooms' or more 10% of public dwellings R+1 au R+5 (max)	[34];[67];[71];[59]
	Connections to city center	Distances of the NZED from city center	Average distance between 2-3km from the city center for the urban areas and 3-8km from the city center for the suburban areas	[56]
Amenities	Green spaces	Expressed in: m2 spaces/number of inhabitants in NZEDs	30% to 50% of the site surface and 30% to 40% in suburban areas	[56];[66];[66];[58]
	Collective spaces	Number of collective (public) spaces in NZEDs	700m around the site's limits	[56]
	Infrastructure/ Services for disable persons	Number of services provided for disable persons	10% of dwellings accessible to disable persons	[72]
Energy	Conception of districts with low energy consumption	Urban structure including dwellings with low energy consumption	Average consumption: ≤60 kWh/m²/y (heating) Electricity: ≤20 kWh/m²/y	[66];[57];[73];[74]
	Energy production by renewable energy resources	Maximization in the use of natural resources for the energy production in the district	Combination in the use of natural resources and the installation of various systems	[57]
Water	Recuperation of storm water	Objective for the reduction in water consumption	100lt/day/pers	[57];[62]
Waste	Waste reuse	Collection and revalorisation of waste for the energy production	60m from the residential dwellings 100kg/person/year	[34];[62]
Systems	'Smart' installation of systems for the reduction of energy consumption	Energy Water Waste	Heating: Solar panels/captures Wind turbines Thermal solar panels Electricity: Photovoltaic panels Cogeneration Water	[75];[57];[76];[77];[78];[65];[79]

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 23 July 2019 doi:10.20944/preprints201907.0257.v1

KPIs	Criterion(a)	Description	U-ZED Approach	References
			Cisterns Recuperation Waste Production biogas	

3.5 Methods and Tools

In Fig. 16, we schematize the general concept of the U-ZED approach. As analysed before, at the second phase of the U-ZED application we develop a roadmap towards the zero energy transition in districts within the use of tools and methods, as we will describe in this section.

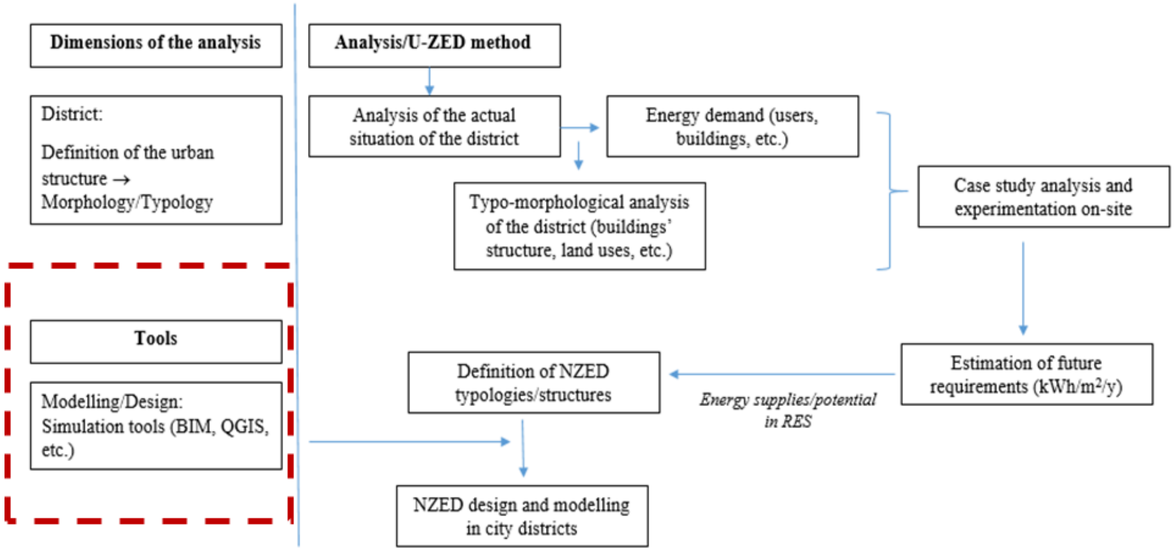

Figure 16. General description of the U-ZED approach

3.5.1 QGIS tool

Urban planning includes functions and land uses, levels, sectors, etc. Indeed, the scale of planning an agglomeration includes most frequently sectors of the urban planning. At each scale of the city planning, there are different phases combining the determination of the objectives of city stakeholders and users, the analysis of the current situation with the use of spatial queries mapping the different city functions and the spatial modelling for the development of planning implementation as well as the phase of assessment and monitoring. All these stages and at all these scales the modelling with QGIS is prerequisite. Chuvieco [80] argues that the association of the spatial optimization models with the use of GIS formulates and develops the planning options in an attempt to maximize or minimize the objectives of the city planning. GIS, however, is also indispensable in a multi-criteria decision analysis to provide the technical inputs in the selection of planning options among diverse scenarios connected to the city planning and its objectives [81]. As a toolbox, GIS allow planners and architects to perform the spatial analysis with the use of different actions and the integration of diverse factors (Fig. 17).

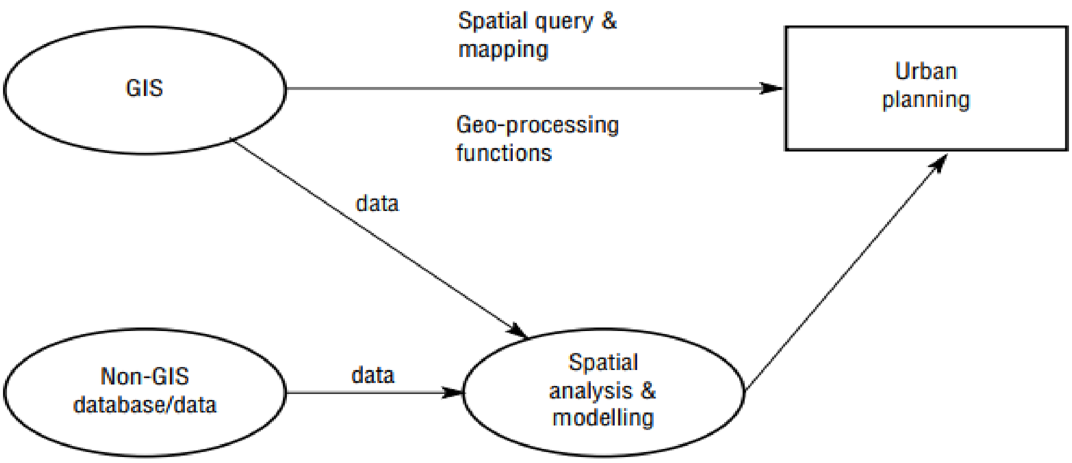

Figure 17. Urban planning and GIS use

3.5.2 HOMER

Bahramara et al. [82] claim HOMER as a powerful tool for energy planning in cities with the aim at determining the optimal size of its elements through a techno-economic analysis considering the components in grid-connected. HOMER requires six (6) types of data for its simulations and optimizations including the: meteorological data; the load profiles; the attributes of the equipment included; the space; the economic and other technical data as Fig. 18 explains.

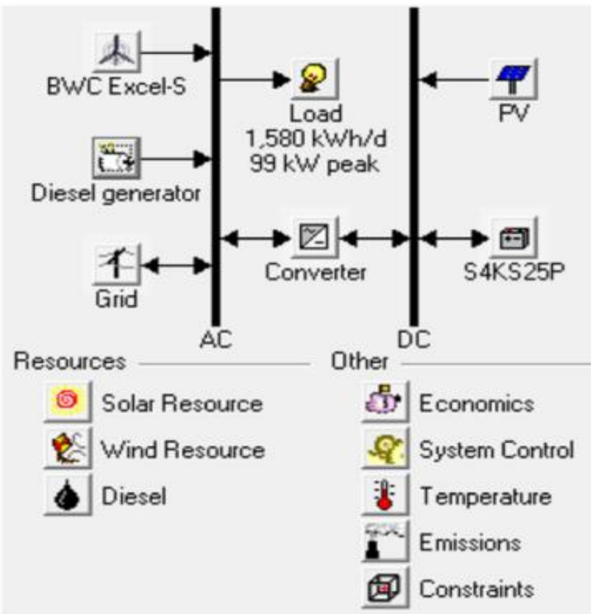

Figure 18. Typical schematic of HOMER's components

3.5.3 The method of Degree Days

Karayiannis [83] explains at his works that the method of Degree Days is mainly used for estimating the heating energy demand in buildings for nearly 70 years. Moreover, attempts have been made to formalize the energy consumption monitoring targeting in buildings. The way in which the method of Degree Days is applied involves assumptions and approximations introducing the uncertainties into the problem. It is expected that the method of Degree Days provides the smallest contribution to errors and it is important to quantify this contribution. Four main approaches are used for the calculation of the Degree Days:

- Mean daily degree hours including integration or summation of hourly record.
- Mean daily temperature from daily maxima and minima.

- Meteorological office equations.
- Hitchin's formula.

For this study, we used the website of the Degree Days methodology by using the meteorological data of the Uccle Station. The findings of the calculations are provided in Section 4 of this paper.

4. Case study Analysis

4.1 The Case study of Epinlieu in Mons. Description of the current situation

The District of Epinlieu is situated 2.5km from the center of Mons with a good proximity to services and infrastructure at its surroundings. Generally, in the district of Epinlieu regarding its demographic evolution, we remark:

- The majority of its population between the age of: 39-69
- An interesting category of young people at the group age of 0-19 years

Concerning the household composition in the district of Epinlieu, the largely dominant category is the two-person households, however, we also find households of larger sizes. These are mostly isolated and mono-parental households.

4.2 Analysis of the urban and built environment of the district in its current situation

4.2.1 Building morphology

The urbanization in the district is being developed along these axes within a composition of the building typology including both single-family and terraced houses, apartment blocks and some other infrastructure and services for its residents (Fig. 19 and 20):

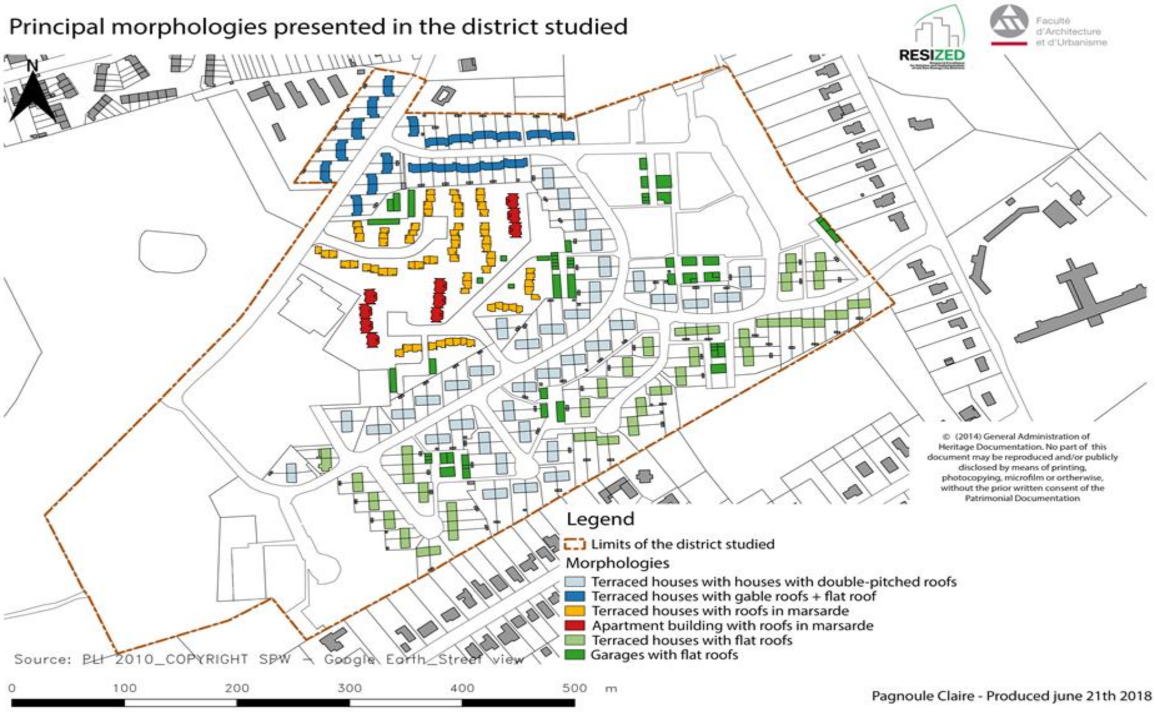

Figure 19. Principal morphologies in the district of Epinlieu (Mons)

The majority of the buildings in the district of Epinlieu are constructed in 1967 for military requirements, with a redevelopment proposed by the Master Plan in 80s in line with Walloon region.

 doi:10.20944/preprints201907.0257.v1

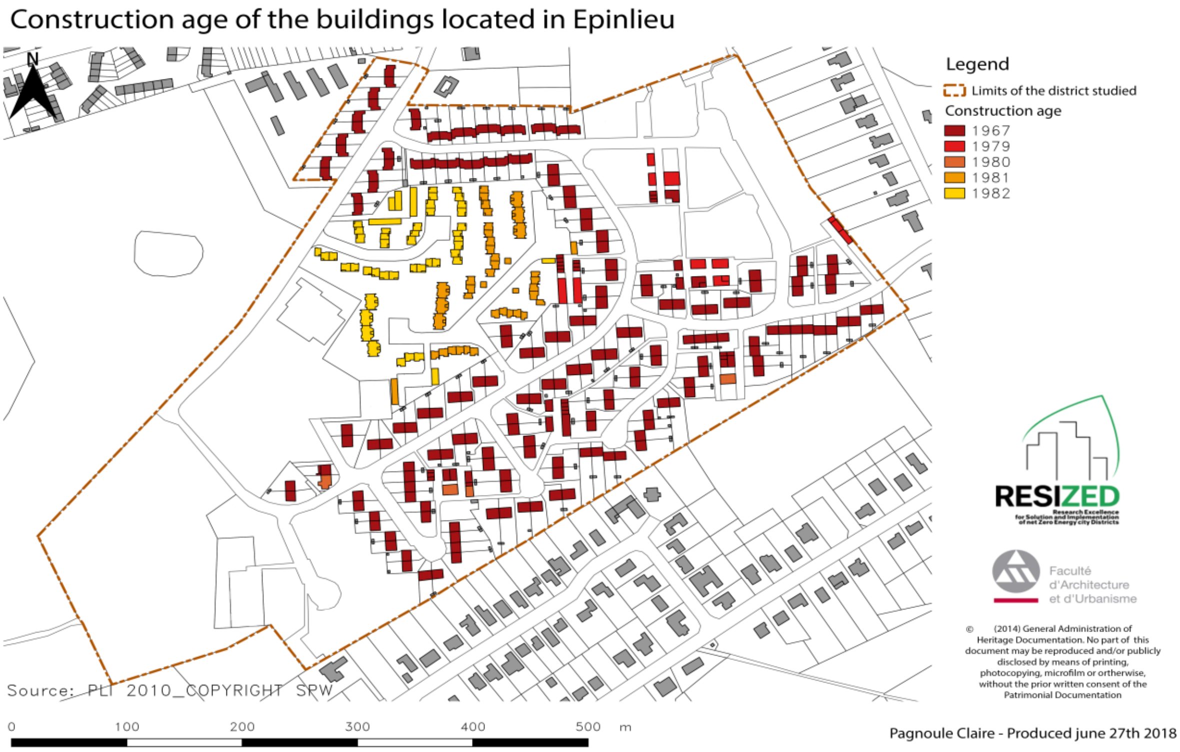

Figure 20. Analysis of construction age of built environment

4.3 Transition towards the Zero Energy Objectives: the Case study of Epinlieu

4.3.1 Focus on 'Energy Autonomy'

The main objective of our study is the 'energy transition' of the district and the application of the U-ZED approach proposed at the framework of this thesis. To do so, we analysed and mapped the results concerning the heating and the electricity consumption of the current dwellings of the district. For the first, we used the method of 'Degree Days'. Applying the method of 'Degree Days' for a typical weather profile, we estimate the 'Heating Degree Days' for the period 01/08/2017 to 01/08/2018 (Fig. 21). In this section, an estimation of heat demand per building typology is performed based on the 'Degree Days' method. For a standard weather profile attributed to the under study region, a 'Heating Degree Days' demand is estimated on an upper and lower boundary, accounting for variations of the actual U value corresponding to the analysed building typology, since U values were imported from TABULA and introduced to the calculations for the period 01/08/2017 to 01/08/2018 (Fig. 21). By this means, it is possible to suggest interventions on the district level aiming to align with the KPI "Conception of districts with low energy consumption" indicated average heat consumption per dwelling.

~~The main objective of our study is the 'energy transition' of the district and the application of the U-ZED approach proposed at the framework of this thesis. To do so, we analysed and mapped the results concerning the heating and the electricity consumption of the current dwellings of the district. For the first, we used the method of 'Degree Days'. Applying the method of 'Degree Days' for a typical weather profile, we estimate the 'Heating Degree Days' for the period 01/08/2017 to 01/08/2018 (Fig. 21):~~

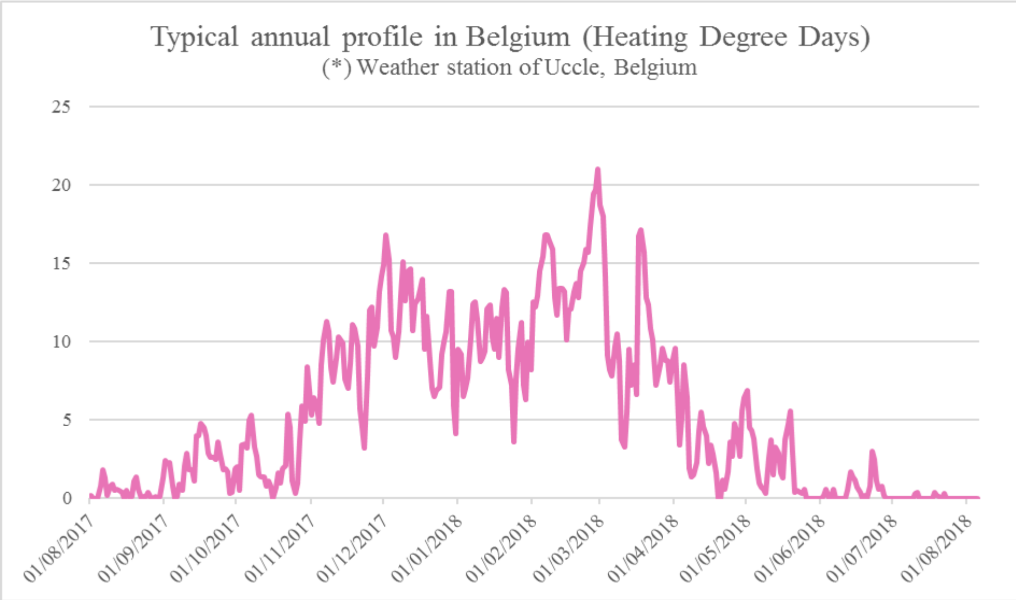

Figure 21. Typical annual profile of Heating Degree Days in Belgium (period: 01/08/2017 to 01/08/2018)

Table 4 presents the calculations of the average energy requirements in the district of Epinlieu (kWh). In Appendix A the authors present the analysis of the energy requirements per each building typology in the district of Epinlieu. The typo-morphologies presented actually in the district are:

- Type 1: Terraced houses with gabled roofs (74 dwellings)
- Type 2: Terraced houses with flat roofs (70 dwellings)
- Type 3: Terraced houses with gabled roofs and parking (40 dwellings)
- Type 4: Terraced houses with mansard roofs (70 dwellings)
- Type 5: Apartments (10 blocks)

Table 4. Calculations of average energy requirements in diverse typo-morphologies in Epinlieu

Month	*Type 1*	*Type 2*	*Type 3*	*Type 4*	*Type 5*
Jan	8.388,11	70.087,93	85.793,92	208.049,81	132.042,70
Feb	111.530,12	87.449,17	107.045,62	259.585,08	164.750,53
Mar	93.693,50	73.463,73	89.926,19	218.070,56	138.402,56
Apr	46.744,24	36.651,49	44.864,71	108.796,69	69.049,85
May	30.547,77	23.952,07	29.319,48	71.099,59	45.124,69
Jun	19.681,79	15.432,21	18.890,40	45.809,13	29.073,62
Jul	15.991,45	12.538,67	15.348,45	37.219,92	23.622,32
Aug	17.426,58	13.663,93	16.725,88	40.560,17	25.742,27
Sep	37.928,44	29.739,15	36.403,38	88.278,02	56.027,29
Oct	43.873,98	34.400,96	42.109,86	102.116,19	64.809,95
Nov	81.392,38	63.818,60	78.119,69	189.439,85	120.231,55
Dec	97.178,82	76.196,52	93.271,37	226.182,59	143.551,01
Total	**685.377,17**	**537.394,42**	**657.818,96**	**1.595.207,61**	**1.012.428,35**

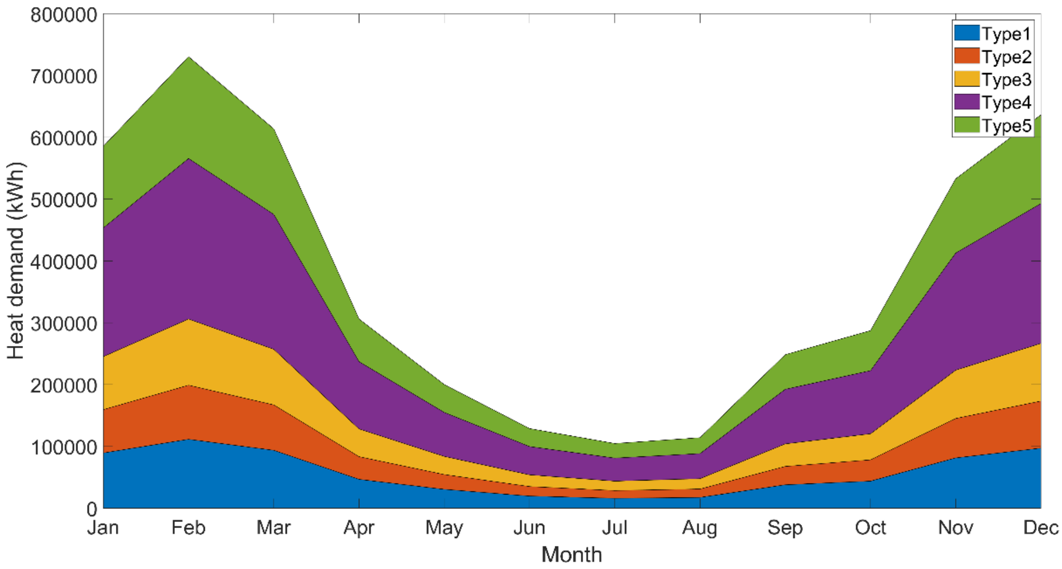

Figure 22. Average energy requirements in the diverse typo-morphologies of the district of Epinlieu

4.4 Transition to the Zero Energy Objectives

Following the analysis of the district's heating energy demand, an annual electricity consumption model per dwelling was devised, providing complementary input for sizing proposed renewable generation solutions aiming to reduce grid dependency and upgrade energy performance. Due to local constraints, large centralized RES unit installations are omitted from this study, since district free construction space would be allocated for functional mixing. As a result, a solution with PV arrays integrated on building rooftops is proposed. Nonetheless, opting to efficiently allocate generated energy, the proposed household system is coupled with an electrical storage component, which counter-balances intermittent factors in renewable generation, such as discrepancies in solar irradiation forecasted profiles. Furthermore, a criterion of rooftop orientation was set, in order to assure an efficient PV generation profile, hence, only west east and south facing rooftops are considered. In turn, the garage with flat roofs typo-morphologies as already defined were excluded due to rooftop installation restrictions.

In the scope of sizing the solar panel installation per typology, the study included indicators such as: the temperature and solar irradiance; etc. Three types of annual loads are calculated per typology based on the average consumption. Energy flow data is provided on an hourly basis for an average year. Specifically, for the typology (including terraced houses with flat roofs and houses with double-pitched roofs) it was calculated at 5,566 kWh/yr. For the types 1 and 2 6,123 kWh/yr and finally the large apartment blocks with roofs in marsarde 22,264 kWh/yr are required. Fig. 23 shows the estimated distribution of annual power consumption per type in the district of Epinlieu.

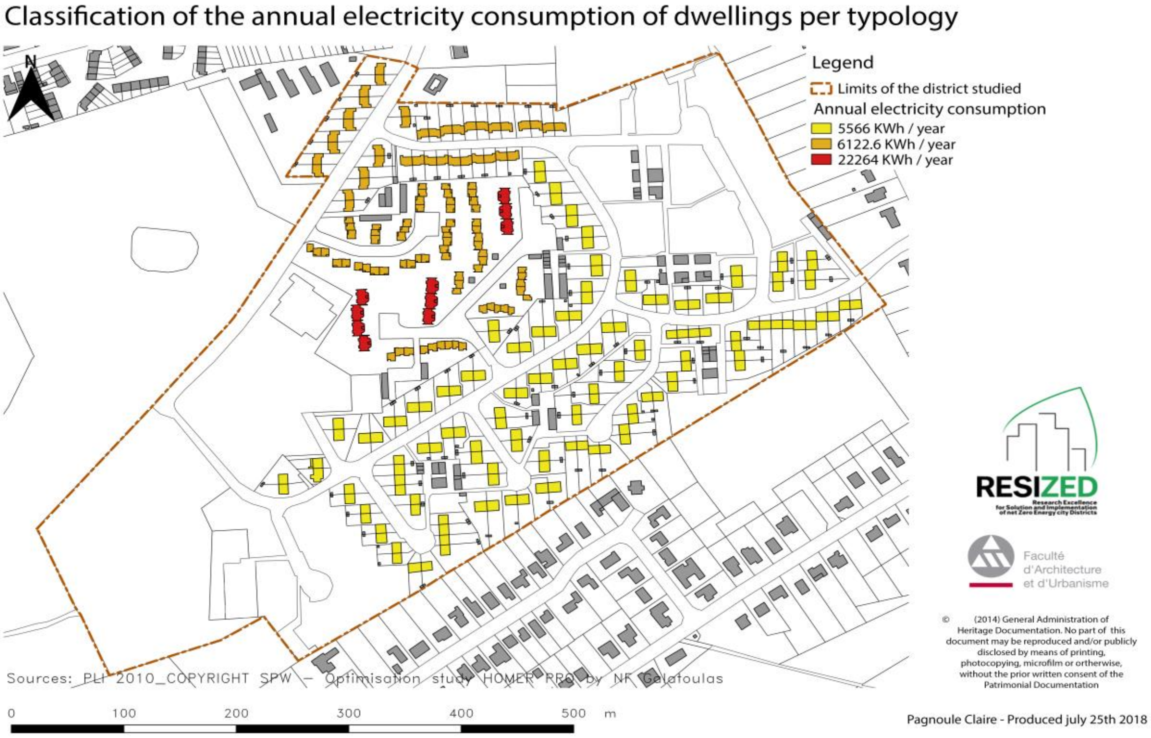

Figure 23. Analysis of profile of the electricity requirements in Epinlieu

With the completion of the pre-processing of inputs, the corresponding systems per dwelling categories were optimized in terms of net present cost and renewable generation components as well as storage capacity. All system configurations consider a grid connectivity option for covering power demand in cases of unmet demand due to generation shortages, meantime permitting transactions with the grid operator (i.e selling stored excess energy) and thereby optimized with respect to the NPC on a 10-year project lifetime. The net present cost (or value) of the system is the present value of all the costs it occurs over its lifetime, minus the present value of all the revenue it earns over its lifetime. Discount and inflation rates were set at 2% and 1%, respectively, accounting for a 0.99% real discount rate over the project lifetime. The levelized cost of energy (COE) represents the cost of the system per kWh over the project lifetime. Other costs considered were capital costs, replacement costs, operating and maintenance costs, while cashflows include also salvage value at the final year. The rates per kWh were set at 0,275 €/kWh and 0.0116 €/kWh, according to the defined tariff policy for Belgium [84]. HOMER ranks all systems configurations by NPC in the optimisation results. Thus, it was decided to compare the annual non-renewable electrical consumption per house with the annual generation profile of the proposed renewable generation system. Consequently, the energy saving per household alongside the necessary costs for retrofitting conclude the analysis.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 23 July 2019 doi:10.20944/preprints201907.0257.v1

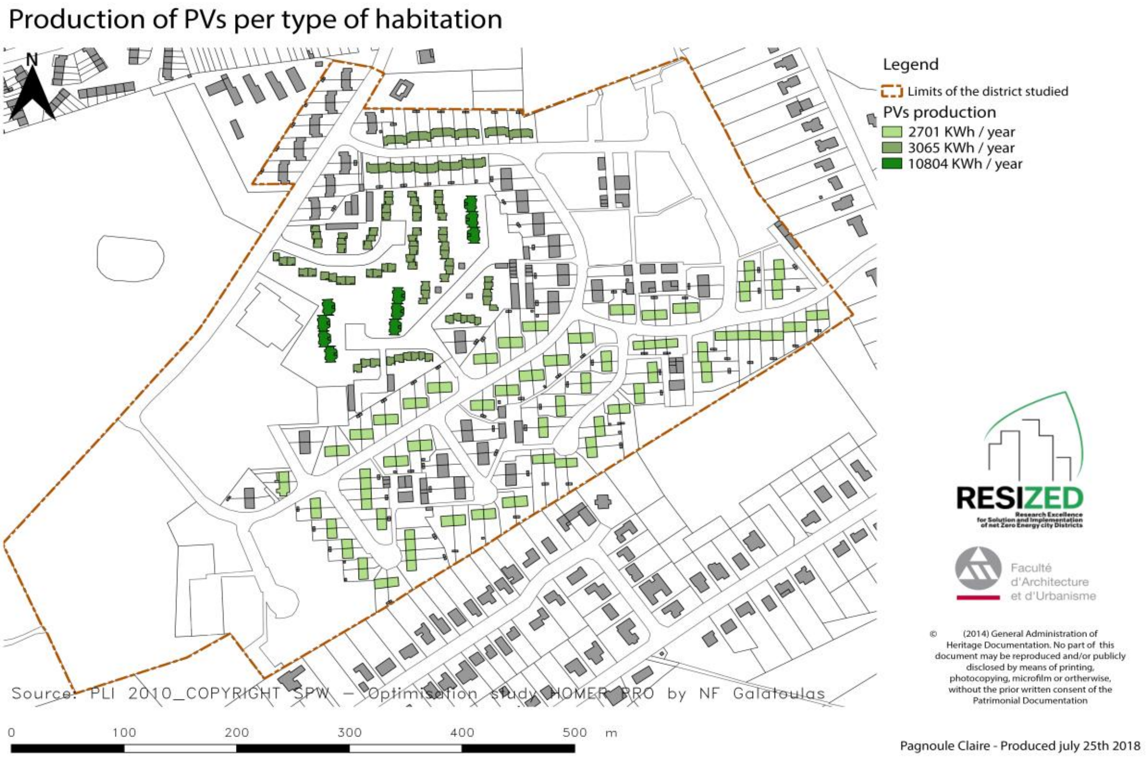

Figure 24. Analysis of PV production per typo-morphology in the of Epinlieu

The area size of a 16.7 % efficiency PV module (325 W rated capacity) is equivalent to 1.951 m2 with a 42 gCO_2e/kWh carbon footprint attributed to upstream manufacturing processes [85]. It can be observed that in the cases of small and average buildings (Table 5), the percentage of annual energy savings is lower than the expected percentage from the simulated PV output. This demonstrates the effect of enabling grid sales on the net present cost optimization, which in turn oversize the investigated system as well as the effects of the load following strategy for serving electric load. Moreover, renewable generation is not aligned with demand (peaks in generation are in summer, contrary to demand peaks), therefore the excess energy is either stored in the battery module where loses are present or if maximum SoC has been reached, then it is depleted. Nonetheless, these results yield the lowest grid purchases meantime maximizing the renewable fraction per system, while similar results occur when disabling the grid sales option and using a storage module, which is in agreement with the relevant KPI defined. Importantly, the retrofitting costs per type of dwelling in terms of initial capital cost were recorded as follows: 9,886 € for the small typology, 10,032 € for the medium and 15,454 € for the apartment buildings.

Table 5. Summary of PV installation specifications per building typology

Household type	Estimated annual electricity consumption (kWh/yr)	Calculated PV output (kWh/yr)	PV installation surface area (m^2) module size Peimar SG325P	Levelized Cost of Energy (€/kWh)	Annual Energy Savings (%)
Small	5,566	5,763	35.118 (5.72 kW)	0.294	72.2%
Average	6,123	5,474	33.167 (5.42 kW)	0.290	67.3%
Large bloc	22,264	14,999	89.746 (14 kW)	0.230	47.2%

 doi:10.20944/preprints201907.0257.v1

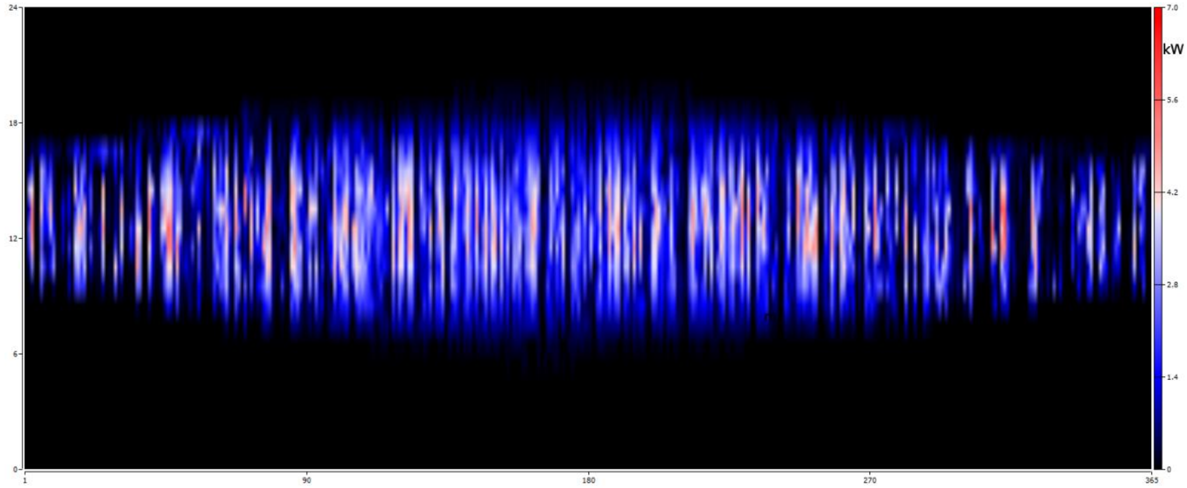

Figure 25. Annual profile of PV installation power output for small typology in the district of Epinlieu

Further improvements regarding sizing of the installations and retrofitting costs can be introduced by disseminating the averaged annual consumptions to precise consumption data from smart meters along with detailed occupancy information, extending market research on more efficient and lower cost PV modules and the consideration of switching to energy distributors that provide energy produced from renewable sources [86]. Last, the selection of an efficient electric storage component would raise the annual savings and reduce grid dependency.

In Fig. 26, the projected amenities of the U-ZED application in Epinlieu are presented. The diagnostic site analysis revealed a dysfunctional district without attractive amenities and with excessive energy requirements by its users. In our proposal, the urban re-arrangement of the agglomeration focuses on the re-organisation of its functions with the proposal of new facilities (for instance an entertainment zone, etc.) in zero energy standards.

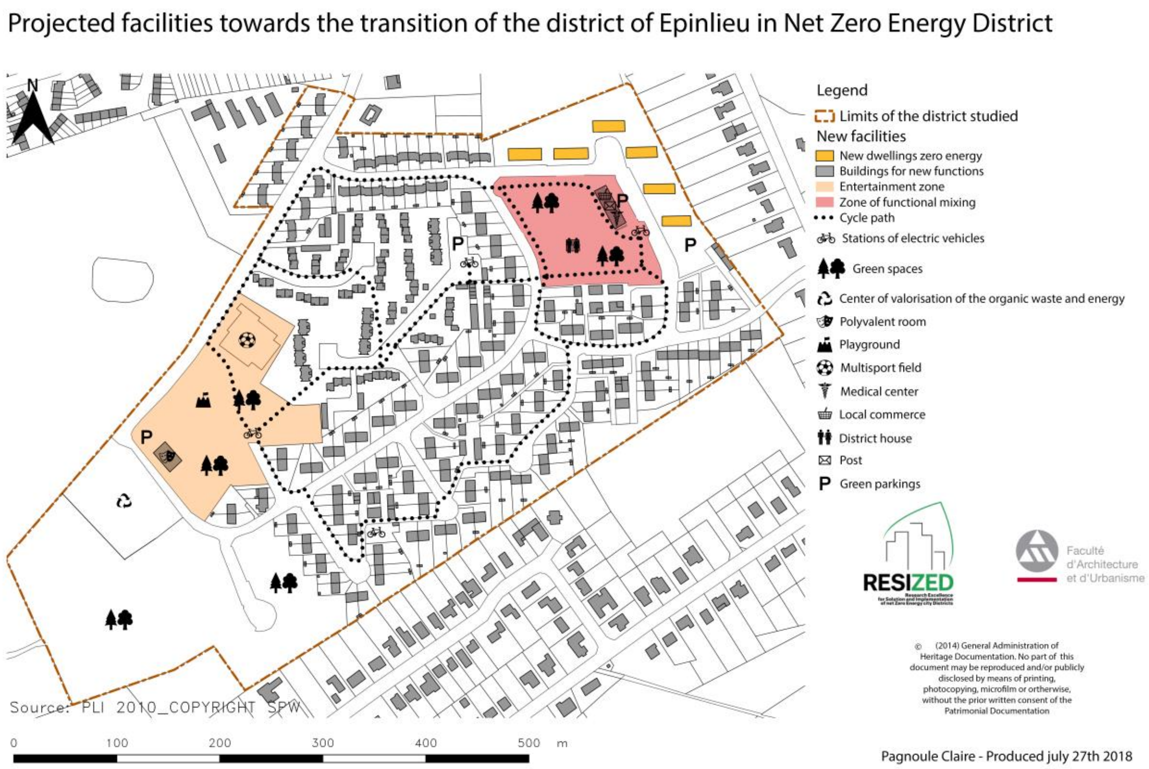

Figure 26. Projected amenities and facilities towards the transition of the district of Epinlieu into the zero energy concept

4. Conclusions

The rapidly growing world energy use has already raised concerns over supply difficulties, exhaustion of energy resources, heavy environmental impacts, climate change, etc. Undoubtedly, reducing energy demand proves more difficulties than it is commonly assumed. Complex systems require necessarily large flows. In this paper, we assume the correlation between the energy consumption and the typo-morphological structure in an existing district towards its transition to a multi-functional and more energetically efficient and autonomous district.

Various effects and mechanisms of the urbanization process show substantial impacts on urban structures and the energy consumption. The current research study investigates the opportunity to extend the 'zero energy' concept to larger territorial scales by proposing a theoretical approach with spatial (and other) dimensions towards the 'optimal' structure (typology and morphology) of the zero energy district. Although, the idea can be conceptualized to a district in a similar approach as individual buildings by articulating its main energy uses, the concept remains complicated and challenging for contemporary cities. This implies innovative approaches towards an interdisciplinary planning that highlight the importance of the zero energy concept and aid the city stakeholders and urban planners to define these particular structures. Indeed, the interrelation between urban structure and energy is a key aspect towards this path. Related to this, a 'well-structured' area is a key point to increase sustainable transport, the share of renewable resources as it affects the land use efficiency and the possibilities towards the sustainable development of the future city districts.

In this study, we analyzed the pilot project the district of Epinlieu (Mons, Belgium) as demonstration of our methodological approach towards the transition to zero energy concept. We simulated the analysis and modelling of NZED models testing various indicators and interconnections among them in the case study of Epinlieu with the recommendation of a smart planning strategy and its implementation and application in city districts towards the transition to zero energy objectives.

Replying to the U-ZED's research questions, we developed different phases in our analysis: (1) the Diagnostic Study with the assessment of the actual situation in respect to indicators, such as the geographical location, the building typology, etc., (2) the Transition Phase towards the zero energy application. Replying to the U-ZED's research question for the district of Epinlieu, we summarize the study in the phases below:

- Phase 1: Diagnosis and assessment of the current (actual) situation: we define the geographical location of the district as provided at the actual situation of the district (definition of the perimeter of the district/research limits, location in regards to its surroundings with the city of Mons and the other districts, etc.). At the Phase 1 of the U-ZED application and the analysis, we defined the spatial organisation of the existing district, we study the site opportunities in respect to the potential energy inventory, the weather conditions, the natural resources towards its 'transition' to the zero energy objectives.
- Phase 2: the problematic of 'geographical location'. Epinlieu: 'smartly' located or not? Posing the question of the 'smart' location of the existing district of Epinlieu, the topography of the site is advantageous. The district is situated 2.5km from the center of Mons with a good proximity to services at its surroundings and well connected by the mild means of transport. The study of the district's transition recommends the improvement of the bus frequency as well as the introduction of the bicycle by tracing cycle paths and even the electric bicycle and the installation of stations serving the district. The district has been developed for the military service requirements with a limited functional mixing (residential) but its strategic location is a key factor for the enhancement of its future attractiveness.
- Phase 3: Analysis of the three pillars of action via the U-ZED approach: the core of the U-ZED analysis with the study of the actual situation in respect to the current energy demand (users' requirements) taking into account the site opportunities and the possibilities for energy storage. In the case of Epinlieu district the problematic of this analysis reveals the lack of valid data because of security and confidential issues, for instance the energy consumption per building, etc. To solve this, we developed methodological assumptions and used existing

tools in the scientific review to identify the energy demand (for instance the method of Degree Days, etc.). In regards to district's offer and opportunities in energy inventory, we are limited only on the solar energy; this is the main reason why we propose at the phase of the district's transition technologies and systems around the exploitation of the solar energy, for instance the photovoltaic panels, etc.

The application of the U-ZED approach for an existing district, as the case of Epinlieu included the identification of the actual situation in a multi-criterion context (with a focus on 'smart typology'), as presented previously, and in particular:

- Building typology: Typo-morphological analysis of the existing building stock in the district of Epinlieu. As presented previously, five typologies are 'met' in the district with an interesting diversity in architectural and construction design and physical composition. The analysis included also the criterion of the roof orientation to define the possibilities of the angle maximising the solar gain with the possibilities of installing PVs. The criterion of compactness is not studied in a depth analysis but only in respect to the diverse typologies in the district.
- Functions: The criterion of functional mixing is part of the analysis of the current situation in the district of Epinlieu. The analysis reveals the problematic of a residential district without diversity in complementary activities for its users, for example commercial, offices or other services or infrastructure.
- Density. The criterion of density is not studied at the current analysis.

This study contributes to this scientific discussion of the linkage of energy and urban structure between the beneficial influence of the city district form to increase the energy efficiency and to indicate the role of the urban planning to affect the 'optimal' structure purposefully. Notwithstanding, limitations concerning mainly the lack of data and the complexity of the applicability of the zero energy concept in larger scales in an effort to include all the potential KPIs have been an important restriction and a weakness for this study. The human factor and the public awareness as well as the participation process are significant for successful policies, as the zero energy concept in districts. Further research and works are required in the future in this particular and major issue for the longevity of modern cities and the achievement of their sustainable objectives.

Acknowledgments

This work has received funding by the European Commission under the RESIZED (Research Excellence for Solutions and Implementation of Net Zero Energy City Districts) project, as part of Grant Agreement no 621408.

Author Contributions

Sesil Koutra, Claire Pagnoule, Nicolaos-Fivos Galatoulas and Ali Bagheri conceived the methodologies towards the transition of the district to the zero energy objectives; Claire Pagnoule performed the cartographical analysis of the district in its diagnostic and projected situation. Thomas Waroux provided explanations for the QGIS tool and its use for the study. Vincent Becue and Christos S. Ioakimidis provided suggestions and supervised the study. Sesil Koutra and Nicolaos-Fivos Galatoulas wrote the paper.

Conflicts of Interest

The authors declare no conflict of interest

Appendix A. Analysis of heating energy requirements in the district of Epinlieu

The study included the calculations for the five (5) building typologies of the district by month to define the annual profile of the energy demand in the district of Epinlieu. The figures below provide the generated data per building/typo-morphology and the heat loss through conductive elements for each of the categories defined previously. In this paper, the degree-days method is used to calculate the conductive heat loss by assuming the constant indoor temperature of 20°C in dwellings throughout the whole year [1]. In the rest of the paper, we use the term heat demand to describe the results for conductive heat loss calculations.

Typo-morphology 1: Terraced Houses with gabled roofs (74 units)

Table 6: Calculations of energy requirements for terraced unit(s) with gabled roofs

Month	*Degree Days*	*Area of losses(m^2)*	*U (W/m^2K)*	*UAmin (W/K)*	*Energy demand for 1 building (D_{1min}) (KWh)*	*Energy demand for all buildings (D_{tmin}) (KWh)*	*UAmax (W/K)*	*Energy demand for 1 building (D_{1max}) (KWh)*	*Energy demand for all buildings (D_{tmax}) (KWh)*
January	436	262,36	0,44	92,36	966,36	71.510,49	138,53	1.449,54	107.265,73
February	544				1.205,73	89.224,09		1.808,60	133.836,14
March	457				1.012,90	74.954,80		1.519,35	112.432,20
April	228				505,34	37.395,39		758,01	56.093,09
May	149				330,25	24.438,22		495,37	36.657,33
June	96				212,78	15.745,43		319,16	23.618,14
July	78				172,88	12.793,16		259,32	19.189,74
August	85				188,40	13.941,26		282,59	20.911,90
September	185				410,04	30.342,75		615,06	45.514,13
October	214				474,31	35.099,18		711,47	52.648,78
November	397				879,92	65.113,91		1.319,88	97.670,86
December	474				1.050,58	77.743,05		1.575,87	116.614,58
				Total	**7.409,48**	**548.301,74**		**11.114,22**	**822.452,61**

Explanations
$\mathbf{UA_{min}}$ = 0,8 X U X S
$\mathbf{UA_{max}}$ = 1,2 X U X S
$\mathbf{D_{1min}}$ = (UA_{min} X Degree Days X 24)/1000
$\mathbf{D_{1tmin}}$ = Number of units X D_{1min}
$\mathbf{D_{1max}}$ = (UA_{max} X Degree Days X 24)/1000
$\mathbf{D_{1tmax}}$ = Number of units X D_{1max}

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 23 July 2019 doi:10.20944/preprints201907.0257.v1

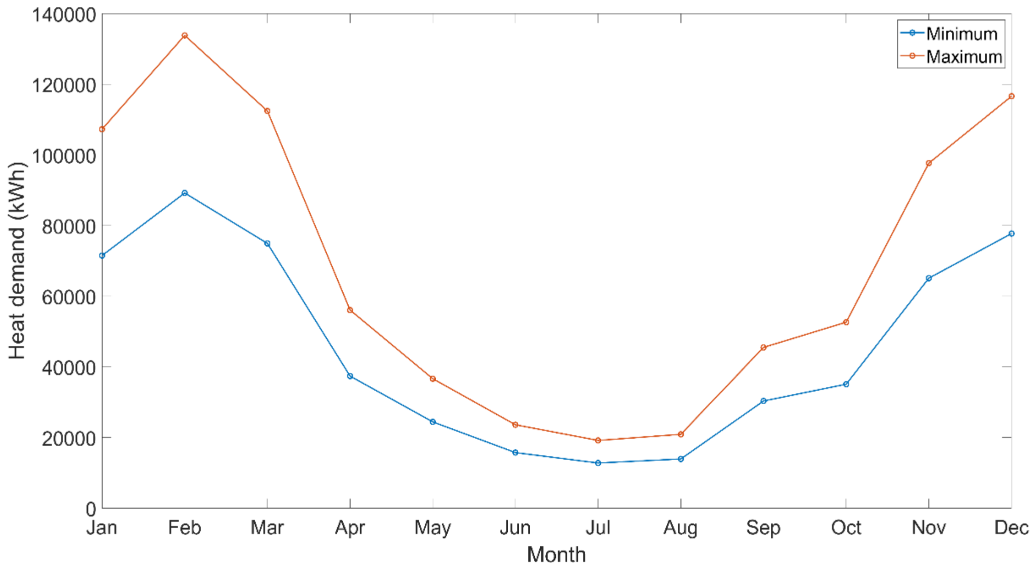

Figure 27. Energy demand of terraced houses with gabled roof in the district of Epinlieu per month (kWh)

Typo-morphology 2: Terraced Houses with flat roofs (70 units)

Table 7. Calculations of energy requirements for terraced unit(s) with flat roofs

Month	*Degree Days*	*Area of losses(m²)*	*U (W/m²K)*	*UAmin (W/K)*	*Energy demand for 1 building (D_{1min}) (KWh)*	*Energy demand for all buildings (D_{tmin}) (KWh)*	*UAmax (W/K)*	*Energy demand for 1 building (D_{1max}) (KWh)*	*Energy demand for all buildings (D_{tmax}) (KWh)*
January	436				801,00	56.070,35		1.201,51	84.105,52
February	544				999,42	69.959,33		1.499,13	104.939,00
March	457				839,59	58.770,98		1.259,38	88.156,48
April	228				418,87	29.321,19		628,31	43.981,79
May	149				273,74	19.161,66		410,61	28.742,48
June	96	233,38	0,41	76,55	176,37	12.345,76	114,82	264,55	18.518,65
July	78				143,30	10.030,93		214,95	15.046,40
August	85				156,16	10.931,15		234,24	16.396,72
September	185				339,88	23.791,32		509,81	35.686,98
October	214				393,15	27.520,77		589,73	41.281,15
November	397				729,36	51.054,88		1.094,03	76.582,32
December	474				870,82	60.957,21		1.306,23	91.435,82
				Total	**6.141,65**	**429.915,53**		**9.212,48**	**644.873,30**

Explanations
$\mathbf{UA_{min}}$ = 0,8 X U X S
$\mathbf{UA_{max}}$ = 1,2 X U X S
$\mathbf{D_{1min}}$ = (UA_{min} X Degree Days X 24)/1000
$\mathbf{D_{1tmin}}$ = Number of units X D_{1min}
$\mathbf{D_{1max}}$ = (UA_{max} X Degree Days X 24)/1000
$\mathbf{D_{1tmax}}$ = Number of units X D_{1max}

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 23 July 2019 doi:10.20944/preprints201907.0257.v1

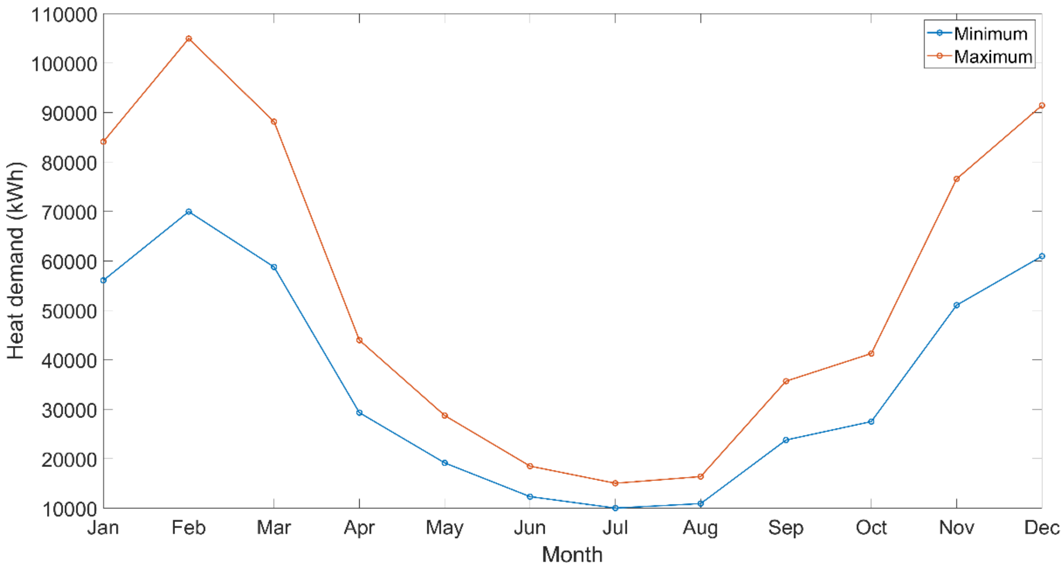

Figure 28. Energy demand of terraced houses flat roof in the district of Epinlieu per month (kWh)

Typo-morphology 3: Terraced houses with gabled roofs and parking (40 units)

Table 8. Calculations of energy requirements for terraced unit(s) with gabled roofs and parking

Month	*Degree Days*	*Area of losses(m²)*	*U (W/m²K)*	*UAmin (W/K)*	*Energy demand for 1 building (D_{1min}) (KWh)*	*Energy demand for all buildings (D_{tmin}) (KWh)*	*UAmax (W/K)*	*Energy demand for 1 building (D_{1max}) (KWh)*	*Energy demand for 1 building (D_{tmax}) (KWh)*
January	436				1.715,88	68.635,13		2.573,82	102.952,70
February	544				2.140,91	85.636,50		3.211,37	128.454,75
March	457				1.798,52	71.940,95		2.697,79	107.911,43
April	228				897,29	35.891,77		1.345,94	53.837,65
May	149				586,39	23.455,58		879,58	35.183,38
June	96	266,2	0,77	163,98	377,81	15.112,32	245,97	566,71	22.668,48
July	78				306,97	12.278,76		460,45	18.418,14
August	85				334,52	13.380,70		501,78	20.071,05
September	185				728,07	29.122,71		1.092,10	43.684,06
October	214				842,20	33.687,89		1.263,30	50.531,83
November	397				1.562,39	62.495,75		2.343,59	93.743,63
December	474				1.865,43	74.617,10		2.798,14	111.925,64
				Total	**13.156,38**	**526.255,17**		**19.734,57**	**789.382,75**

Explanations
UA_{min} = 0,8 X U X S
UA_{max} = 1,2 X U X S
D_{1min} = (UA_{min} X Degree Days X 24)/1000
D_{1tmin} = Number of units X D_{1min}
D_{1max} = (UA_{max} X Degree Days X 24)/1000
D_{1tmax} = Number of units X D_{1max}

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 23 July 2019 doi:10.20944/preprints201907.0257.v1

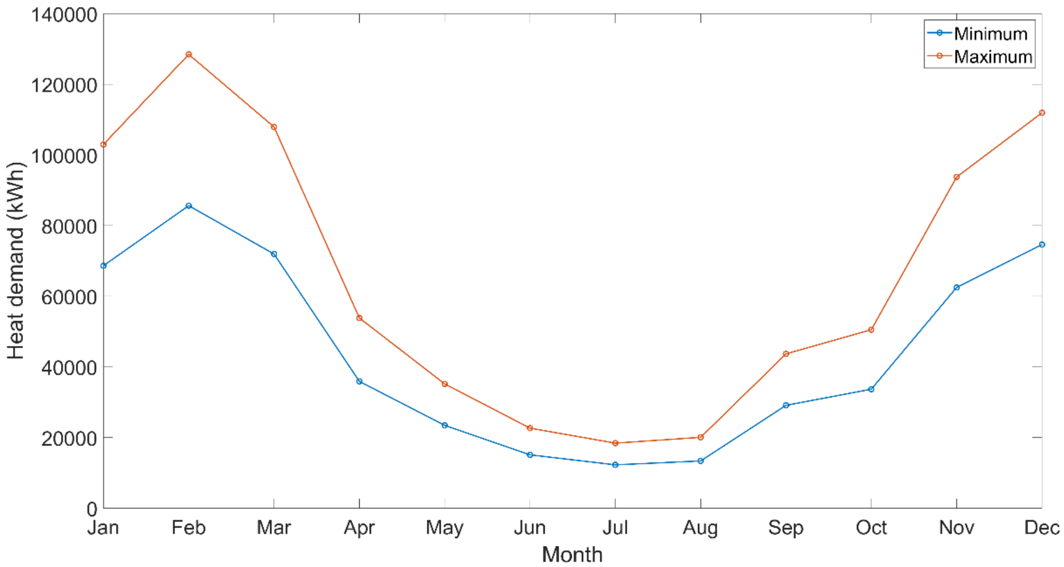

Figure 29. Energy demand of terraced houses with gabled roofs and parking in the district of Epinlieu per month (kWh)

Typo-morphology 4: Terraced houses with mansard roofs (70 units)

Table 9. Calculations of energy requirements for terraced unit(s) with mansard roofs

Month	*Degree Days*	*Area of losses(m²)*	*U (W/m²K)*	*UAmin (W/K)*	*Energy demand for 1 building (D_{1min}) (KWh)*	*Energy demand for all buildings (D_{tmin}) (KWh)*	*UAmax (W/K)*	*Energy demand for 1 building (D_{1max}) (KWh)*	*Energy demand for all buildings (D_{tmax}) (KWh)*
January	436				2.377,71	166.439,85		3.566,57	24.9659,77
February	544				2.966,69	207.668,07		4.450,03	311.502,10
March	457				2.492,23	174.456,45		3.738,35	261.684,67
April	228				1.243,39	87.037,35		1.865,09	130.556,03
May	149				812,57	56.879,67		1.218,85	85.319,51
June	96				523,53	36.647,31		785,30	54.970,96
July	78	213,56	1.33	227,23	425,37	29.775,94	340,84	638,06	44.663,90
August	85				463,54	32.448,14		695,32	48.672,20
September	185				1.008,89	70.622,41		1.513,34	105.933,62
October	214				1.167,04	81.692,95		1.750,56	122.539,43
November	397				2.165,03	151551.88		3.247,54	227.327,82
December	474				2.584,94	180946.07		3.877,42	271.419,11
				Total	**18.230,94**	**1.276.166,08**		**27.346,42**	**1914249.13**

Explanations
UA_{min} = 0,8 X U X S
UA_{max} = 1,2 X U X S
D_{1min} = (UA_{min} X Degree Days X 24)/1000
D_{1tmin} = Number of units X D_{1min}
D_{1max} = (UA_{max} X Degree Days X 24)/1000
D_{1tmax} = Number of units X D_{1max}

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 23 July 2019 doi:10.20944/preprints201907.0257.v1

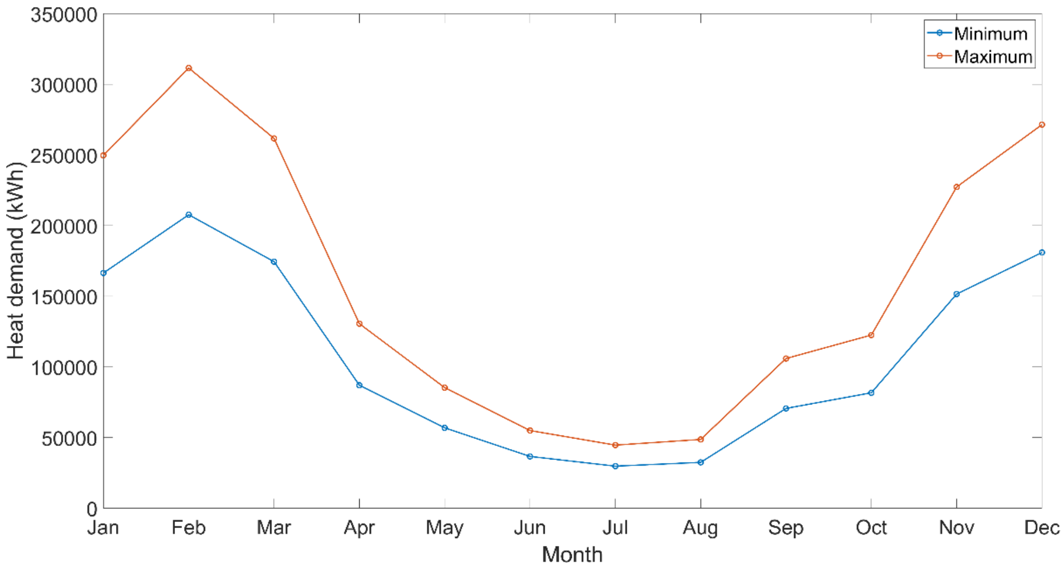

Figure 30. Energy demand of terraced houses with mansard roofs in the district of Epinlieu per month (kWh)

Typo-morphology 5: Apartments (10 units)

Table 10. Calculations of energy requirements for apartments

Month	*Degree Days*	*Area of losses(m²)*	*U (W/m²K)*	*UAmin (W/K)*	*Energy demand for 1 building (D_{1min}) (KWh)*	*Energy demand for 1 buildings (D_{tmin}) (KWh)*	*UAmax (W/K)*	*Energy demand for 1 building (D_{1max}) (KWh)*	*Energy demand for 1 building (D_{tmax}) (KWh)*
January	436	742,28	1,70	1.009,5	10.563,42	105.634,16	1.514,25	15.845,12	158.451,25
February	544				13.180,04	131.800,42		19.770,06	197.700,64
March	457				11.072,20	110.722,05		16.608,31	166.083,07
April	228				5.523,99	55.239,88		8.285,98	82.859,83
May	149				3.609,97	36.099,75		5.414,96	54.149,62
June	96				2.325,89	23.258,90		3.488,83	34.888,35
July	78				1.889,79	18.897,85		2.834,68	28.346,78
August	85				2.059,38	20.593,82		3.089,07	30.890,72
September	185				4.482,18	44.821,84		6.723,28	67.232,75
October	214				5.184,80	51.847,96		7.777,19	77.771,94
November	397				9.618,52	96.185,24		14.427,79	144.277,85
December	474				11.484,08	114.840,81		17.226,12	172.261,22
				Total	**80.994,27**	**809.942,68**		**121.491,40**	**1.214.914,02**

Explanations
UA_{min} = 0,8 X U X S
UA_{max} = 1,2 X U X S
D_{1min} = (UA_{min} X Degree Days X 24)/1000
D_{1tmin} = Number of units X D_{1min}
D_{1max} = (UA_{max} X Degree Days X 24)/1000
D_{1tmax} = Number of units X D_{1max}

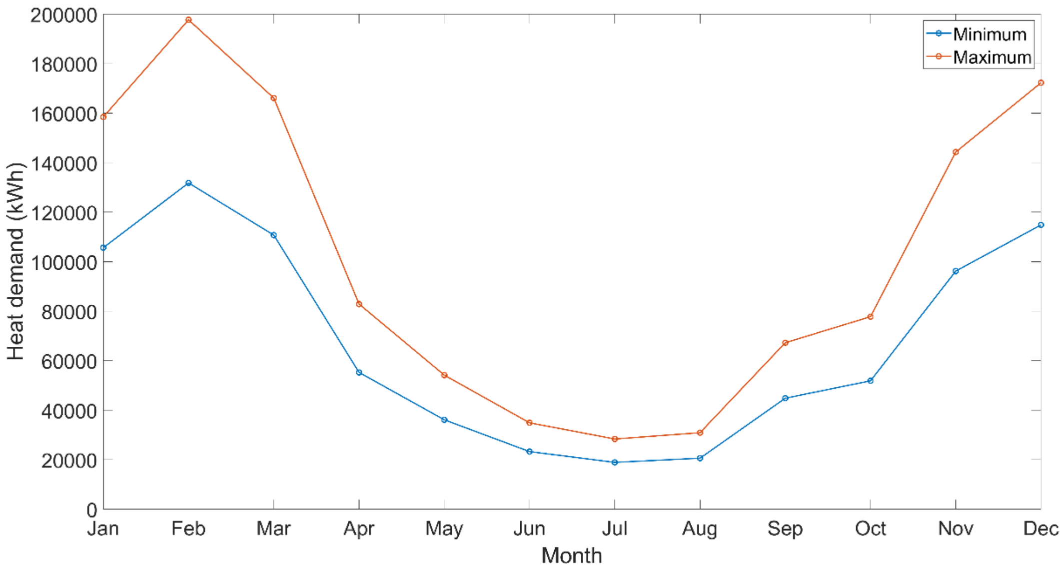

Figure 31. Energy demand of apartments blocks in the district of Epinlieu per month (kWh)

 doi:10.20944/preprints201907.0257.v1

References

[1] H. Girarbet, *Creating Regenerative Cities*, 1st ed. Routledge: Abingdon, 2015.

[2] J. Große, C. Fertner, N. Groth, "Urban Structure, Energy and Planning: Findings from Three Cities in Sweden, Finland and Estonia," *Urban Plan.*, vol. 1, no. 1, pp. 24–40, 2016.

[3] S. Owens, *Energy, planning and urban form*. London, 1986.

[4] S. Salat,"Energy loads, CO2 emissions and building stocks: morphologies, typologies, energy systems and behaviour," *Build. Researcn Inf.*, vol. 37, no. 5, pp. 598–609, 2009.

[5] F. Ewing, R, Rong, "The Impact of Urban Form on U.S. Residential Energy Use," *Hous. Policy Debate*, vol. 19, no. 1, pp. 1–30, 2008.

[6] R. Papa, C. Gargiulo, F. Zucaro, G. Angiello, G. Carpentieri,"Urban energy consumptions: its determinants and future research," *WIT Trans. Ecol. Environ.*, vol. 191, pp. 561–570, 2014.

[7] J. Urquizo, C. Calderon, P. James, "Energy Research & Social Science Metrics of urban morphology and their impact on energy consumption: A case study in the United Kingdom," *Chem. Phys. Lett.*, vol. 32, pp. 193–206, 2017.

[8] N. Baker, Steemers, K., *Energy and environment in architecture: a technical design guide*. 2000.

[9] N. Miller, "Urban form and building energy: quantifying relationships using a multi-scale approach," University of British Columbia, 2013.

[10] G. Mitchell, "Urban Development, Form and Energy Use in Buildings: A review for the SOLUTIONS project," 2005.

[11] K. Steemers, "Energy and the city : density , buildings and transport," *Energy Build.*, vol. 35, pp. 3–14, 2003.

[12] A. Reiter, S., De Herde, A., Marique, "Projet SOLEN: SOlutions for Low Energy Neighborhoods, Un cadre pour la définition du 'quartier zéro énergie' (QZE)," 2014.

[13] B. Amar, Y. Boukedjar, A .El Sharkawi, M. Oubadji, S. Terkia,"Méthode d'analyse: typomorphologie." 2006.

[14] K. Seto, R. Sánchez-Rodríguez, M. Fragkias, "The new geography of contemporary urbanization and the environment," *Annu. Rev. Environ. Resour.*, vol. 35, pp. 167–194, 2010.

[15] W.P. Anderson, P. Kanaroglou, M. Miller, "Urban form, energy and the environment: A review of issues, evidence and policy," *Urban Stud.*, vol. 33, no. 1, pp. 7–35, 1996.

[16] Y. Jabareen, "Sustainable urban forms: their typologies, models and concepts," *J. Plan. Educ. Res.*, vol. 26, no. 3, pp. 38–52, 2006.

[17] A. Moudon, C. Lee, and A. Cheadle, "Operational definitions of walkable neighborhood: Theoretical and empirical insights," *J. Phys. Act. Heal.*, vol. 3, no. February, pp. S99–S117, 2006.

[18] M. Doherty, H. Nakanishi, X. Bai, J; Meyers, "Relationships between form, morphology, density and energy in urban environments," Canberra, Australia, 2009.

[19] P. Rode, "Accessibility in cities: transport and urban form," 2014. [Online]. Available: http://2014.newclimateeconomy.report/wp-content/uploads/2014/11/Transport-and-urban-form.pdf. [Accessed: 25-Aug-2015].

[20] J. Sarralde, J. Steemers, "Solar energy and urban morphology : Scenarios for increasing the renewable energy potential of neighbourhoods in London," *Renew. Energy*, vol. 73, no. July, pp. 10–17, 2014.

[21] UOH (Université Ouverte des Humanités), Université Nice Sophia, Faculté Espaces et Cultures, IMST, GEOPRAD, "L'analyse des espaces publics. Les places," 2013. [Online]. Available: http://www.espaces-publics-places.fr/. [Accessed: 17-May-2016].

[22] K. Athamena, "Modélisation et simulation des microclimats urbains : Etude de l'impact de la morphologie urbaine sur le confort dans les espaces extérieurs. Cas des Eco-Quartiers.," Ecole Centrale de Nantes, 2012.

[23] A. Levy, "Formes urbaines et significations : revisiter la morphologie urbaine," *Espac. Soc.*, vol. 122, pp. 25–48, 2005.

[24] G. Borlin, "Challenges of nearly zero energy in urban areas," Institut Technico of Lisboa, 2013.

[25] LSE, "Cities and Energy. Urban Morphology and Heat Energy Demand," 2014.

[26] I. Sartori, A. Napolitano, K. Voss,"Net zero energy buildings: A consistent definition framework," *Energy Build.*, vol. 48, pp. 220–232, 2012.

[27] D. D'Agostino, "Assessment of the progress towards the establishment of definitions of nearly zero energy buildings (nZEBs) in European member States," *J. Build. Eng.*, vol. 1, pp. 20–32, 2015.

[28] I. Sartori, A. Napolitano, A. J. Marszal, S. Pless, and P. Torcellini, "Criteria for Definition of Net Zero Energy Buildings," *Renew. Energy*, no. September, pp. 1–22, 2010.

[29] P. Torcellini, S. Pless, M. Deru, and D. Crawley, "Zero Energy Buildings: A Critical Look at the Definition," *ACEEE Summer Study Pacific Grove*, p. 15, 2006.

[30] European Union, "Concentrated action: Energy Performance of Buildings (EPBD)," 2010. [Online]. Available: http://www.epbd-ca.eu/. [Accessed: 05-Jan-2015].

[31] A. Amaral, A., Rodrigues, E., Gaspar, A., Gomes, "Review on performance aspects of nearly zero energy districts," *Sustain. Cities Soc.*, vol. 13, pp. 406–420, 2018.

[32] S. Pless, B. Polly, S. Zaleski,"Communities of the Future : Accelerating Zero Energy District Master Planning," 2018.

[33] N. Carlisle, O. Geet, S. Pless, "Definition of a ' Zero Net Energy ' Community," Colorado, 2009.

[34] J. Teller, A.F. Marique, "Des « Quartiers Durables » en Wallonie. Etat d'avancement des travaux relatifs à l'évaluation des projets de quartiers durables," 2014.

[35] P. Becchio, C., Corgnai, S., Delmastro, C., Fabi, V., Lombardi, "The role of nearly-zero energy buildings in the transition towards Post-Carbon Cities," *Sustain. Cities Soc.*, vol. 27, pp. 324–337, 2016.

[36] S. Kilkis, *A Rational Exergy Management Model to Curb CO2 Emissions in the Exergy-Aware Built Environments of the Future*. 2011.

[37] A. Haapio, "Towards sustainable urban communities," *Environ. Impact Assess. Rev.*, vol. 32, no. 1, pp. 165–169, 2012.

[38] Y. Sun, P. Huang, G. Huang, "A multi-criteria system design optimization for net zero energy buildings under uncertainties," *Energy Build.*, vol. 97, pp. 196–204, 2015.

[39] R. Ameen, M. Mourshed, H. Li, "A critical review of environmental assessment tools for sustainable urban design," *Environ. Impact Assess. Rev.*, vol. 55, pp. 110–125, 2015.

[40] S. Koutra, V. Becue, and C. S. Ioakimidis, *A Simplified methodological approach towards the net zero energy district*, vol. 738. 2017.

[41] A. Bosch, P., Jongeneel, S., Rovers, V., Neumann, H., Airaksinen, M., Huovila, "CITYkeys indicators for smart city projects and smart cities," 2017.

[42] M. Alberti, "Measuring urban sustainability," *Environ. Impact Assess. Rev.*, vol. 16, pp. 381–424, 1996.

[43] S. Salat, F. Labbé, C. Nowacki, C.Walker, *Cities and Forms: On Sustainable Urbanism*. Paris, 2011.

[44] C. Ratti, N. Baker, K. Steemers, "Energy consumption and urban texture," *Energy Build.*, vol. 37, pp. 762–776, 2005.

[45] R. Compagnon, "Solar and daylight availability in the urban fabric," *Energy Build.*, vol. 36, pp. 321–328,

2004.
[46] H. Sanaieian, M. Tenpierik, K. Van Den Linden, S. Mehdizadeh, S. Mofidi, "Review of the impact of urban block form on thermal performance, solar access and ventilation," *Renew. Sustain. Energy Rev.*, vol. 38, pp. 551–560, 2014.
[47] N. Foletta, "Västra Hamnen, Malmo, Sweden," 2015.
[48] H. Linck, "Car free experience in Freiburg-Vauban." 2008.
[49] ARENE: Agence régionale de l'environment et des nouvelles énergies, "Quartiers durables:Guide d'expériences européennes," Ile-de-France, Apr-2005.
[50] J. Phildius, "Quel modèle pour un écoquartier à Genève? Etude et analyse de réalisations exemplaires en Europe," EPFL: Ecole Polytechnique Fédérale de Lausanne, 2009.
[51] K. Kaptein, "EVA-Lanxmeer (Culemborg - NL)," in *Guidebook of Sustainable Neighbourhoods in Europe*, Energy Cities, Ed. 2008, p. 29.
[52] J. Rabie, "L'écoquartier Vauban à Fribourg: une démarche globale pour une réalisation exemplaire," 2009.
[53] A. Broaddus, "Tale of Two Ecosuburbs in Freiburg, Germany: Encouraging Transit and Bicycle Use by Restricting Parking Provision," *J. Transp. Res. Board*, vol. 2187, pp. 114–122, 2010.
[54] M. Senel, "Assessment of Sustainable Housing Projects," 2010.
[55] Energy cities, Ed., "Hammarby Sjöstad (Stockholm - SE)," in *Guidebook of Sustainable Neighbourhoods in Europe*, 2008, pp. 21–23.
[56] J. Teller, A.F. Marique, V. Loiseau, F. Godard, C. Delbar, *Référentiel Quartiers Durables*. SPW éditions, Guides Méthodologiques, 2014.
[57] "ATESTOC : Stockage d'énergie thermique en aquifère pour la réalisation d'éco-quartier," 2011.
[58] J. Kildsgaard, I, Jarnehammar, A., Iverfeldt, A., Green, "SECURE: Sustainable Energy Communities in Urban Areas in Europe," 2008.
[59] C. Schulz, "' Urban Design for Sustainability : Learning from Helsinki ,'" 2006.
[60] Foletta, N., Field, S., "Europe's Vibrant New Low Car (bon) Communities," 2010.
[61] "Pic-Au-Vent: Un nouveau quartier de 36 maisons passives à Tournai." 2010.
[62] H. Rinne, "Eco-Viikki (Helsinki - FI)," in *Guidebook of Sustainable Neighbourhoods in Europe*, E. Cities, Ed. 2008, pp. 27–28.
[63] H. Mönninghoff, "Sustainable neighbourhood - Kornsberg (Hanovre – DE)," in *Guidebook of Sustainable Neighbourhoods in Europe*, E. Cities, Ed. 2008, pp. 11–12.
[64] J. Stigt, "GWL-Terrein (Amsterdam - NL)," 2008. [Online]. Available: http://energy-cities.eu/IMG/pdf/GWL-Terrein__Amsterdam-NL_.pdf. [Accessed: 12-Jun-2015].
[65] S. Field, "Case study: Vauban Freiburg, Germany," 2010.
[66] G. Yepez-Salmon, "Construction d'un outil d'évaluation environnementale des écoquartiers: vers une méthode systémique de mise en oeuvre de la ville durable," Bordeaux 1, 2011.
[67] ARCEA, "Rapport Urbanistique et Environnemental ZACC 'Bon Air,'" 2016.
[68] T. Reiter, S., Marique, AF, De Herde, A, De Meester, "SOLEN (SOlutions for Low Energy Neighbourhoods): L'objectif zéro énergie: un état de l'art," 2014.
[69] C. Laroche, "« Penser et mettre en œuvre la mixité sociale comme outil du vivre ensemble » Contribution du Conseil de développement," 2010.
[70] C. Chouvet, "Les quartiers durables : Etude des freins et des leviers de la diffusion de ce modèle d' aménagement," Paris, 2007.

 doi:10.20944/preprints201907.0257.v1

[71] Ministère du logement, de l'égalité, des territoires et de la ruralité, "La démarche ÉcoQuartier," 2014.

[72] C. Ruelle, A.F.Marique, "La durabilité à l'échelle du quartier," Liège, 2014.

[73] S. Pandis Iverot and N. Brandt, "The development of a sustainable urban district in Hammarby Sjostad, Stockholm, Sweden?," *Environ. Dev. Sustain.*, vol. 13, no. 6, pp. 1043–1064, 2011.

[74] Service Public de Wallonie - DGO4, "Plan d'Action NZEB en vue de la transposition de l'article 9 du Recast de la Directive Européenne relative à la performance énergétique des batiments," Namur, 2010.

[75] L. Fränne, "Hammarby Sjöstad–a unique environmental project in Stockholm," 2007.

[76] G. Austin, "Case study and sustainability assessment of Bo01, Malmo, Sweden," *J. Green Build.*, vol. 8, pp. 34–50, 2009.

[77] F. Vasseur, C., Poulet, G., Gingreau, C., Louçano, "BedZED: un quartier écologique au sud de Londres," 2008.

[78] C. Malamatenios, "Energy saving - Solar energy villages – the example of Greece," 2008. [Online]. Available: http://indiaenergyportal.org/files/CS128.pdf. [Accessed: 05-May-2015].

[79] J. Degraeve, "Habiter en quartier durable: Pratiques et stratégies d'action pour un nouvel ancrage local du logement," 2011.

[80] E. Chuvieco,"Integration of Linear Programming and GIS for Land-Use Modelling," *Geogr. Inf. Syst.*, vol. 7, no. 1, pp. 71–83, 1993.

[81] A. Yeh, "Urban planning and GIS," 1990.

[82] S. Bahramara, M. Moghaddam, M. Haghifam, "Optimal planning of hybrid renewable energy systems using HOMER: A review," *Renew. Sustain. Energy Rev.*, vol. 62, pp. 609–620, 2016.

[83] T. Karayiannis, "Degree-days : Comparison of calculation methods," *Build. Serv. Eng.*, vol. 19, no. 1, 1998.

[84] Eurostat, "Electricity prices for household consumers - bi-annual data," 2018. .

[85] C. Jones, P. Gilbert, "Determining the consequential life cycle greenhouse gas emissions of increased rooftop photovoltaic deployment," *J. Clean. Prod.*, vol. 184, pp. 211–219, 2018.

[86] T. Huld, R. Muller, A. Gambardella, "A new solar radiation database for estimating PV performance in Europe and Africa," *Sol. Energy*, pp. 1803–1815, 2012.