From smart ground to smart grid: A method to achieve multi-enegy system

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***Abstract*—During the last two centuries, the urban percentage of the world's population, combined with the overall growth phenomenon, has deeply increased and it is projected to reach 60% by 2030. In this current context linked to environmental issues managing to plan sustainable cities appears a main policy target. The European Climate and Energy package foresees a substantial reduction of energy consumptions in buildings by 2020. The implementation of Net Zero Energy Buildings (nZEBs) as the building target from 2018 onwards represents one of the biggest challenges to increase energy savings and minimize greenhouse gas emissions. The aim of this paper is the development of a methodological approach about energy management in a district to the potential of a 'smart ground' towards the development of a 'smart city'. This work opens and addresses numerous future research perspectives that should be investigated widely to develop districts with an operational and long-term context.**

***Index Terms*-- district, ground, net-zero, smart**

I. Introduction

Energy oriented innovations and practices, regulative instruments and incentives are emerging in modern cities to respond to phenomena as the dispersed urbanization and its impacts (e.g. CO2 emissions, etc). In an approved legislative framework, the European Parliament proposes that by 31.12.2020 all new buildings shall be of nearly or net zero-energy consumption and that will have to produce as much energy as they consume on-site [1].

The Zero Energy Building (ZEB) principle is anticipated to contribute significantly towards the achievement of the future 'smart cities', envisioned by the European Union and promoted through its regulatory framework [2]. The strategy 'Energy 2020' affirms that 'the well-being of people, industry and economy depends on safe, secure, sustainable and affordable energy'. It confirms, therefore, the targets '20-20-20' defined in 2007 by the European Council, aimed at reducing greenhouse gases by 20%, increasing renewable energy to 20% and making a 20% improvement in energy efficiency [3].

Consequently, the major challenge, today, is the adaptation and retrofitting of the existing building stock in order to reach an annual zero-energy balance, at the district scale and in highlighting the urban and architectural parameters that act upon its energy balance for energetically autonomous and autarchic districts.

The paper focuses on the challenge of the districts' transformation into more sustainable with the introduction of the 'smart ground' term. The methodology includes the analytical steps towards the achievement of a 'smart ground' with limited energy consumption. The hybridization of the 'smart' location and morphology with the alternative use of multi-energy systems is the key factor. Two additional pillars complete this approach and concern: (1) the optimization of occupants' needs and (2) the organization of storage (energy, water, etc).

The paper is structured accordingly. Section II identifies the net-zero energy concept exploring its components and need for application. Section III analyzes the operational context of a district and 'smart ground'. Section IV includes the methodological approach of the net-zero energy district based on literature review and previous observations, while Section V summarizes the main points and findings that emerged from the previous review.

II. Net-zero energy concept

The achievement of a low carbon or energy district depends not only on the energy performance and sustainability of the new and existing building stock but also to a significant extent on the sustainability of the urban planning and infrastructure. Commercial and residential buildings are estimated to consume approximately 40% of the total primary energy and to be responsible for 24% of greenhouse emissions in Europe [4]. Specific measures to reduce energy consumption in the building sector have been introduced and proposed for its long-term improvement by 2020.

The European legislative framework for buildings adopt definitions and national policies for their application towards the net-zero energy policy [5]. The concept is basically concentrated on a building level. In the literature review, more than 300 projects in a building level worldwide are registered [6]. The concept has gained international attention during the last few years and it is now seen as the future target for their construction and design. However, before being fully implemented in each country's national building codes and international standards, the ZEB concept requires clear and consistent definition and a commonly agreed energy calculation methodology.

The most important issues before developing a ZEB definition are: (1) the metric of the balance, (2) the balancing period, (3) the type of energy use included in the balance, (4) the type of energy balance, (5) the accepted renewable energy supply options, (6) the connection to the energy infrastructure and (7) the requirements for the energy efficiency and the indoor climate [7].

Generally speaking, a building or a cluster of buildings, depending on where the system boundary is put, it is characterized by a certain load, but also by some sort of energy generation (Figure 1) [8]. The load includes the efficiency of technical installations and not only the net energy demand. The generation, likewise, includes storage and conversion losses. A building is assumed to be in steady state over a year regardless of the balance between load and generation. Renewable energy sources available on-site are used passively to partially satisfy the building's load. These on-site renewables are also used to generate energy carriers that in part cover the load and are fed back into the grid, depending on the temporal matching between generation and load and the available storage possibilities. The concept of balance between delivered and feed-in energy, together with any form of interaction with the grids is central in the definition of ZEB. Hence, the import and export shown can be expressed as follows [7]:

$$\text{Import} = \Sigma_i \text{ delivered energy (i)*credits (i)} \quad (1)$$

$$\text{Export} = \Sigma_i \text{ feed – energy (i) *credits (i)} \quad (2)$$

where i= energy carriers

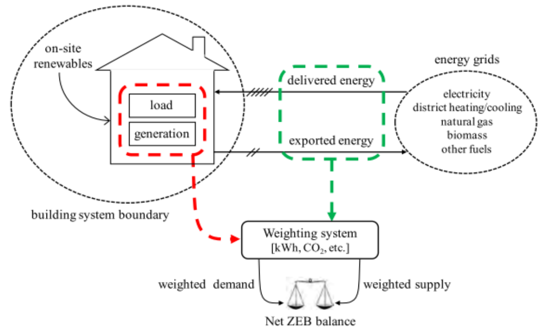

Figure 1. Presentation of the balance of a NZEB [8]

The review of the existing ZEB definitions and the proposals for calculation methodologies indicates the complexity of the concept, the lack of common agreement as well as emphasizes the key issues that should be deliberated and clarified before the further deployment of a ZEB, while at the same time the need for deeper analysis to explore the concept in larger scales.

III. FROM NET-ZERO ENERGY BUILDING TO NET-ZERO ENERGY DISTRICTS

A. The district scale

Sustainability of the built environment is by no means restricted to questions regarding the location of buildings and urban densification. In this context, the district level, which stands between the city and the building levels, appears to be particularly interesting in operational terms. It is indeed well suited to experiment with the specific practices aimed to improve the sustainability of the urban environment [9] but also the application of the net-zero energy concept.

Valdieu and Outrequin [10] define the district as 'a cluster or ensemble of built and urban environment'. The concept of 'district' in an urban context includes the following basic characteristics:

- The inhabitants have a sense of community or belonging to the community, which is derived from local centers, services and the sense of place or specific symbolic elements, district life, etc
- Urban consciousness, social and political participation
- Economic characteristics (local economy)
- Area's functions and role in the city (part of a global district network and of the whole city)
- Physical cohesion created by its architectural style and the arrangement of its public spaces
- Urban morphology and topography

Generally, the 'district scale' is a micrography of a city and one of its constructive elements. It has all the characteristics of an autonomous and coherent system, socially and functionally mixed with symbols, historical features and morphology. By addressing targeted issues, this approach results in innovative solutions [9] with the introduction of modern technologies and multi-energy applications.

At a 'district scale', there are few cases including the 'zero' concept but mainly focused on zero carbon emissions without the use of fossil fuels (e.g. the case of the eco-district BedZED, Sutton, UK, etc). Most of them are called 'sustainable districts' or 'eco-districts' but in their initial targets a balance of 'zero energy' does not exist. With a view to the overall quality of living conditions, the promotion of the return to the city raises multi-dimensional questions that must be incorporated into the processes of their urban transformation [9].

B. The need for a 'smart city'

The future of the majority of citizens' is undeniable urban. Fascinating the urban development is already taken place in the notion of 'smart city'. In essence, the 'smart city' is built on three pillars [11]:

1. Make quality of life an excellence hub.
2. Promote sustainable development through harmonized public services, which will increase productivity and energy savings.
3. Work on economic development.

The urban futures strand showed that technology has always played an important role in forward-looking visions about the future city and its districts as well as its constructive components (infrastructure, buildings, etc.). The knowledge and innovation showed that recent technological advancements have introduced a whole new level of management and innovation capabilities in the city context.

Angelidou [11] outlined the technology push and the demand pull for smart city solutions. A 'smart city' is a complex system driven by diverging interests and made up by: the use of 'smart energy' towards intelligent ways for the energy reduction, 'smart buildings' using innovative technologies (efficient energy appliances for heating, cooling, etc), 'smart transport' or 'Intelligent Transport Systems' (ITS) including smart vehicles technologies within the encouragement of green mobility and zero carbon policies [11].

C. The notion of 'smart ground'

The innovative notion of 'smart ground' is defined in accordance with the development of effectively performed districts towards the 'smart grid' and 'smart city' and symbolizes the hybridization of technologies, multi-energy systems and renewable energy produced on-site for a district. The 'smart ground' is guided by two (2) strategic axis concerning:

I. The 'smart' location (the question of the localization of the district and the variables regarding the resources, the potential, the inventory, the climate, etc)
II. The 'smart' morphology (the question of the urban typology of the district concerning the 'form' of 'smart ground' regarding its orientation, compactness, buildings' geometry, etc)

Both axis target the development of 'intelligent' district ('smart ground'). These two fundamental issues frame the holistic diagnosis of the district as an urban project and the concept of its 'smartness' regarding the parameters that influence the perspectives of its implementation in real life (occupants, stakeholders, etc).

Figure 2 presents the general framework towards the NZED (Net-Zero Energy District) highlighting the roles of 'location', 'morphology' and 'technology' to concretely operationalize its concept.

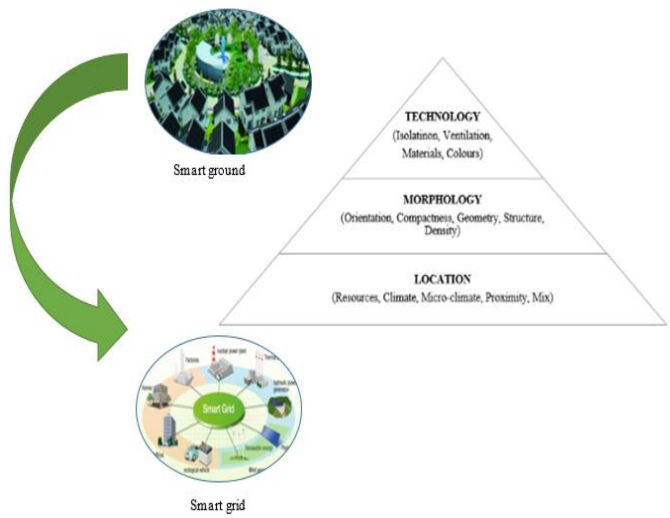

Figure 2. From the 'smart ground' to the 'smart grid'

IV. METHODOLOGY

The 'energy question', the use of renewable energy sources and the energy performance have been calculated in a building scale. Several papers propose thus definitions of Zero Energy Buildings calculation methodologies [12] or support tool for early stages of design [13]. These definitions are commonly articulated around an annual energy balance equal to zero. These models adopt, in general, the perspective of a building considering that it is autonomous neglecting the importance of phenomena that appear to broader scales (district, city, etc). However, if the holistic urban context is ignored, the building approach is not adequate as the most important policy decisions are taken in larger and more strategic urban scales (district, city, country).

A. The systemic approach of the district

For this study, the district is understood as an 'urban block' and a complicated system with various parameters, while the Net-Zero Energy District aiming at articulating the main energy uses: building energy consumption, production of on-site renewable energy and transportation energy consumption [14] and it is consisted by components with interesting interactions (Figure 3):

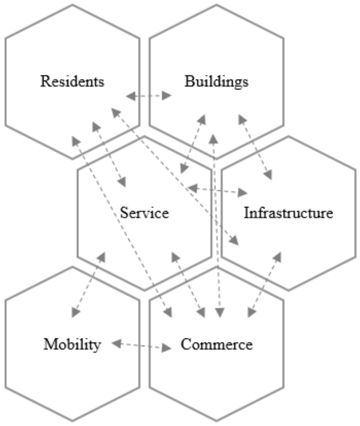

Figure 3. Components and interconnections of a district

B. The Net-Zero Energy District

The definition of the net-zero energy concept in terms of urbanism is connected to the geographical scale. The zero-energy balance is thus considered as a whole and each building is not necessarily a zero-energy building [14]. The National Renewable Energy Laboratory defined, in a technical report, a 'Zero Energy Community' (ZEC) as 'one that has greatly reduced energy needs through efficiency gain such that the balance of energy for vehicles, thermal, and electrical energy within the community is met by renewable energy' [15].

The size of the district is not limited but it should be eventually related and coherent to the current and existent urban forms in all levels. It is not particular but it is necessary to achieve the habitat mixing and the diversity of urban functions ensuring the environmental quality [16].

Marique and Teller [17] underline that the 'Net-Zero Energy District' concept is described, by analogy with the Net-Zero Energy Building, as a 'district in which annual energy consumption for buildings and transportation of inhabitants are balanced by the local production of renewable (and other forms) energy'. The balance is annual but monthly balances are also studied to capture the gaps between energy consumption and production by renewable sources. Transportation-related fuel consumption is also minimized. Production potential area of energy is developed to a maximum offset, at a minimum, all the primary energy consumption due to the operation and use of buildings and daily passenger transportation. As far as the metric of the system is concerned, the balances are proposed in terms of primary energy. Note also that a net zero-energy district connects interactions among the buildings inside the system and its surroundings [17].

The most important elements of a NZED are described by the following equations [18]:

Building energy consumption: the annual Energy Consumption for Space Heating (ESH), Energy for Space Cooling (ECO), Energy for Ventilation (EV), Energy for Appliances (EA), Energy for Cooking (EC) and Energy for Domestic Hot Water (EDHW). The district's annual Energy consumption for Buildings (EB) is calculated using (3):

$$EB = ESH + ECO + EV + EA + EC + EHW \quad (3)$$

Production on-site renewable energy: on-site Energy production via Photovoltaic Panels (EPV), Energy for Thermal Panels (ETH) and Energy for small Wind Turbines (EWT) are considered when accounting for renewable energy sources. The annual renewable Energy produced in the District (ED) is calculated using (4):

$$ED = EPV + ETH + EWT \quad (4)$$

Transportation energy consumption: the annual Energy Consumption for Daily Mobility (EDM) is assessed using a performance index introduced by Boussauw and Witlox [19]. This index is expressed in kWh/travel per person and represents, for a territorial unit, the mean energy consumption for travelling for one person living within a particular neighborhood. This index takes into account the distances travelled, the means of transportation used and their relative consumption rates, as expressed by:

$$\text{Energy performance index (i)} = \Sigma m= Dmfm/Ti \quad (5)$$

In the (5), i represents the territorial unit, m the means of transportation used (diesel car, gasoline car, train, bus, bike, walking), D_{mi} the total distance travelled by the means of transportation m in territorial unit I, f_m the consumption factor attributed to the means of transportation m and Ti the number of persons in the territorial unit i. The annual energy consumption of the district (ED) is calculated by adding the building energy consumption (EB) and transportation energy consumption (EDM) and subtracting the onsite renewable energy production (ERP), as shown in (6) and this should reach the zero (or be positive).

$$ED = EB + EDM – ERP \quad (6)$$

In this study, the NZED as a 'smart ground' is considered as a complicated urban system with an operational context of a 'smart city' but in a less extended scale (Figure 4). The procedure of the 'smart ground' system includes the consideration of its inputs (inventory, location, etc), its processes inside the district (transportation, etc), its outputs (consumption, CO2 emissions, etc) and the interconnections with its surroundings (connections with the city) in an effort to balance the sum of exported and imported energy from and to the grid.

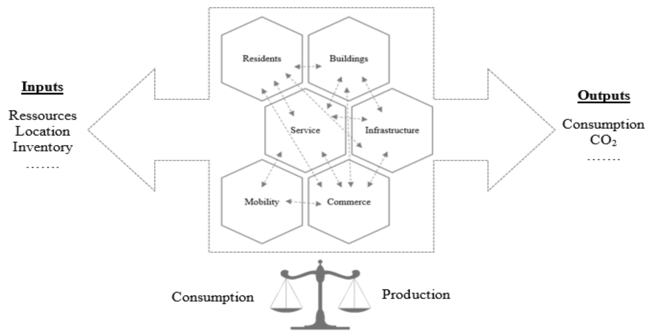

Figure 4. Systemic approach of NZED

The concept of the NZED as presented also graphically (Figure 5) is based on three (3) pillars:

1. *Optimization of needs* by analyzing the key factors for a district (location, morphology, organization, etc) comparing the initial goals with the real consumptions and achievements. This pillar is concentrated on the way to an energetically autonomous district with the control and optimization of the occupants' actual needs (energy, transport, etc).
2. *Use of energetic hybridization* by analyzing the possibility to combine the potential, the energy systems and the technologies used for the energy needs.
3. *Organization of storage by analyzing the energy perfor*mance of the technologies and systems installed. In the framework of a net-zero energy project of an energetically autonomous district, the parameter of storage allows the energy distribution during all the seasons and optimizes its consumption regarding the needs.

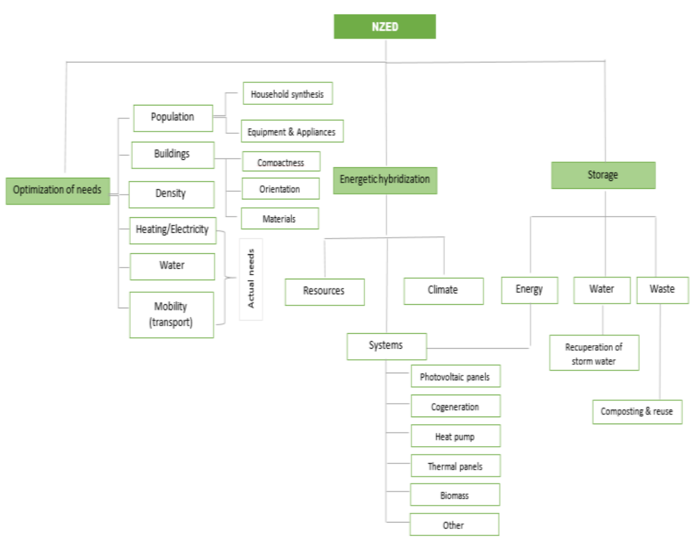

Figure 5. Analysis of the three pillars of a NZED

As the Figure 5 explains, the scope of the NZED is to define and optimize the energy needs as a first step, which are parameters of different variables in the district system and depend on: the population, the household synthesis, the building envelope but also on the systems used for domestic hot water, heating, electricity and cooling needs. Three parameters in terms of the system analysis are defined concerning: the energy, the water and the waste. One of the main principles for the NZED is the sustainability and all the actions needed in this purpose (reuse of waste, treatment of storm water and recycle, use of renewable energy sources, etc). The systemic approach is a general perspective for a better integration of the individual building into its context in policies dealing with energy efficiency. Promoting building and retrofitting of energy efficient buildings is a fundamental step towards NZED but it is not sufficient.

V. DISCUSSION

This paper explores the path from the 'smart ground' to the 'smart grid' as a result of the contemporary urban transformation of the modern districts. It aims at completing the existing review to 'zero energy' concept by investigating its feasibility at a district scale.

Problems as the dispersed urbanization and the poor built and urban environment seem unsustainable in long-term. Holistic approaches in accordance with multi-energy systems and innovative research solutions as the systemic approach of the district and its consideration as 'smart' are mandatory.

This work opens numerous future research perspectives that should be investigated widely to develop NZEDs with a concrete and operational context in real life. The proposed methodological framework will be extended and completed as a further step in the scope of defining and transforming our districts into less polluted and energetically performed, more flexible, efficient with a long-term and sustainable character.

The potential of 'energy mutualisation', energy storage and 'smart grid' remain key challenges of crucial importance in the scope of a net-zero energy objective at the district scale that will be further investigated in a further research program.

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