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New domain for promoting energy efficiency: Energy Flexible Building Cluster

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A R T I C L E I N F O

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A B S T R A C T

The ongoing energy system shift—from traditional centralized fossil fuel based to decentralized renewable energy sources based—requires a strengthened control of energy matching. Smart buildings represent the latest step in building energy evolution and perform as active participants in the cluster/energy infrastructure scale, becoming energy prosumers. In this framework, the IEA EBC Annex 67 introduces the concept of 'Energy Flexible Building', defined as a building able to manage its demand and generation in accordance with local climate conditions, user needs and grid requirements. Currently, there is no insight into how much flexibility a building may offer, and this study aims to overview the theoretical approaches and existing indicators to evaluate the Energy Flexibility of building clusters. The focus on cluster scale allows for the exploitation of the variation in energy consumption patterns between different types of buildings and the coordination of load shifting for the improvement of renewable energy use. The reviewed indicators can contribute to the definition of the Smart Readiness Indicator, introduced in the European Commission proposal for the EPBD revision, in order to test a building's technological readiness to adapt to the needs of the occupants and the energy environment, as well as to operate more efficiently.

1. Introduction

The "Clean Energy for All European" package (EC, 2016a) of the European commission sets out the energy policy framework going toward 2030, and treats buildings as an essential part of Europe's clean energy transition. The principle "energy efficiency first" (EC, 2015) drives the transformation of the conventional centralized energy system based on fossil fuels into an efficient decentralized system powered by renewable energy sources.

Energy systems based on Variable Renewable Energy sources are characterized by intermittent generation, and their rapid increase challenges the stability of both thermal and electric grids (Whiteman, Rinke, Esparrago, & Elsayed, 2016). A mitigating effect of the stress put on the grid by variable renewable energy sources (VRES) penetration can be played by buildings, which are gradually moving from standalone consumers to interconnected prosumers (both producers and consumers) able to provide and store renewable energy and actively participate in demand response.

Despite the fact that the Energy Performance of Buildings Directive (EU, 2010) and the Renewable Energy Directive (EU, 2009) have stimulated the deployment of on-site renewable energy systems, the on-site (or nearby) renewable energy production and self-consumption in European countries are not at their full potential. This is partly due to rigid regulatory frameworks and lack of investments. The instantaneous sharing of produced energy among buildings is allowed or encouraged only in a few Member States and currently the storage technologies are too expensive for massive application. Therefore, it is necessary to identify solutions aimed at changing the relationship between the grid and the consumers. Future buildings should adapt their energy demand to the needs of the grid and the renewable production, while maintaining high comfort standards and low operating costs.

In recent years, we have observed a deep evolution of the building design approach in terms of targets, technology functions, overall performances and domain (Fig. 1). The evolutionary path of building transformation started with *passive buildings* intended to minimize the energy demand through passive solutions (building envelope domain), then evolved into the *nearly Zero Energy Buildings* (nZEB) aimed at obtaining an energy balance (consumption-production) through on-site generation from RES (building as energy system domain) (Paoletti, Pascual Pascuas, Pernetti, & Lollini, 2017), and will now find its latest evolution in the energy matching required by *smart buildings* in order to improve resilient building behavior coupled with grid interaction

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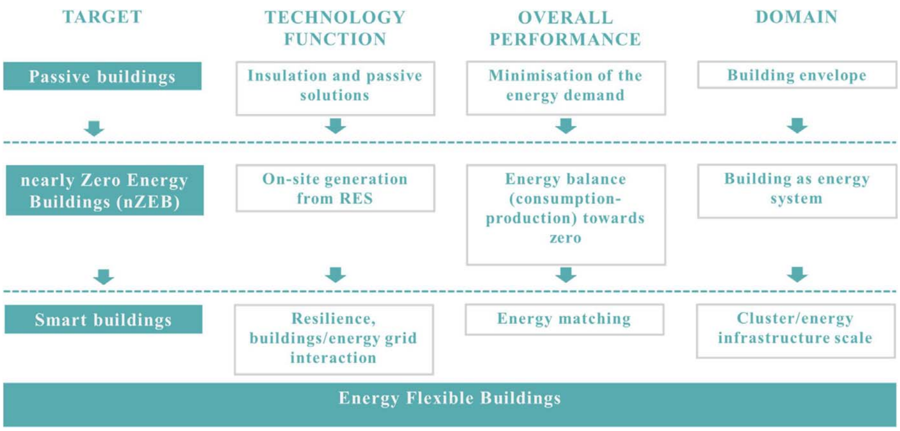

Fig. 1. Evolutionary path of building transformation.

(cluster/energy infrastructure domain).

Within this framework, the International Energy Agency (IEA), in the programme 'Energy in Buildings and Communities' (EBC), introduces the concept of 'Energy Flexible Buildings' with the project 'Annex 67′ (IEA EBC ANNEX 67). Based on the initial definition of Annex 67, building Energy Flexibility represents "the capacity of a building to manage its demand and generation according to local climate conditions, user needs and grid requirements. Energy Flexibility of buildings will thus allow for demand side management/load control and thereby demand response based on the requirements of the surrounding grids".

From a different perspective, Energy Flexibility could also be defined as the capacity of a building to react to one or more forcing factors, in order to minimize CO_2 emissions and maximize the use of Renewable Energy Sources (RES). The forcing factors represent a set of significant boundary conditions that could change during the lifetime of a building and have different levels of frequency:

– Low frequency factors (temporal fluctuations within the years-decades time range): climate change, macro-economic factors, technological improvement, building intended use and variation in the number of occupants, demographic changes (e.g. age, income);
– High frequency factors (temporal fluctuations within the minutes-hours time range): internal loads, solar loads, user behavior, energy prices.

Starting from the initial definition, the work planned within Annex 67 deals with three main topics: metrics and indicators able to represent Energy Flexibility in buildings, simulation and evaluation of technology solutions (passive, active, and control strategies) and the potential influence of user behaviour on an Energy Flexible Building. One of the issues faced within this Annex is the Energy Flexibility assessment at cluster level. It is meant to be an intermediate level between a single building and districts or the whole city, and it offers the possibility to achieve performance enhancement and cost optimization through a mutual collaboration between generation, storage, and consumption units (AIA National, 2007; Crosbie, Short, Dawood, & Charlesworth, 2017; Shen & Sun, 2016).

The present paper aims to make a comprehensive overview of the theoretical approaches, currently described in the literature, for the evaluation of Energy Flexibility of building clusters in order to provide the framework for the performance assessment of the future generation of Energy Flexible buildings. In particular, the section *Energy Flexibility in the European perspective* reports the current EU Commission development of a "Smart Readiness Indicator"; the chapter *Energy Flexible Building Clusters* clarifies the importance of designing at cluster scale, then explains the meaning of the word 'cluster' (definition) and the level of interaction among buildings (connection) and finally reports some key concepts adopted so far in the literature to describe the synergy of energy efficient buildings and renewable energy utilization at an aggregated level; the last section, *Reviewed indicators for evaluating Energy Flexibility at the building cluster level,* focuses on existing metrics and indicators that can be used to quantify Energy Flexibility at cluster scale.

2. Energy flexibility in the European perspective

In addition to being the focus of Annex 67, Energy Flexibility represents a key issue to be addressed also according to the European Commission. Considering the transition toward clean energy, the interaction between buildings and the spread of information to consumers regarding operational energy consumption can contribute to RES maximization at a local level. In this regard, the "Clean Energy for All Europeans" package, the proposal for amending EPBD (EC, 2016b), introduces a 'Smart Readiness Indicator' (SRI). The "Common general framework methodology for the calculation of 'Smartness Indicator' for Buildings" of the proposal for amending EPBD focuses on key SRI functionalities: (*i*) the technological readiness assessment of a building's capacity to adapt to user needs and energy environment; (*ii*) the evaluation of building readiness in operating more efficiently and (*iii*) the measurement of the readiness of building interaction in demand response with the energy system and the district infrastructure.

The introduction of such a SRI will increase building users' consciousness of the fundamental role of smart technologies and ICT solutions, encouraging the spread of healthier and more comfortable buildings with lower energy use and carbon impact, while facilitating RES integration.

The current state of discussion at the EU level evaluates the flexibility according to the number and features of the building components with a qualitative approach, whereas the characterization and methodology defined within the Annex 67 will provide a quantitative evaluation of the flexibility associated with a building, by using measured physical data and results from simulation campaigns. Therefore, the approach being defined within the Annex 67 can be coupled and applied within the framework of the evaluation of Smart Readiness Indicator, providing a quantitative evaluation of the flexibility associated with a building.

In order to properly create the SRI indicator, it is necessary to identify smart services, i.e. services that use smart technologies to facilitate energy management and interact with building occupants' behaviors to fulfil their comfort needs (Verbeke, Ma, Bogaert, Tichelen, & Uslar, 2017). The concept of 'functionality levels' can be introduced to value the smartness of service implementation, ranging from basic functionality to fully integrated smart solutions (Fig. 2).

The review and investigation of Energy Flexible indicators can contribute to defining the proper smart technologies that are able to store thermal and electrical loads, to improve load shifting potential of buildings while maintaining required comfort levels, and support the