# Managing Energy Flexibility Resources in Buildings

Subjects: Engineering, Electrical & Electronic

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The integration of renewable energy and flexible energy sources in buildings brings numerous benefits. However, the integration of new technologies has increased the complexity and despite the progress of optimization algorithms and technologies, new research challenges emerge. Multi-objective optimization is crucial to enhance the utilization of flexible resources within individual buildings and communities.

energy optimization buildings energy communities building energy management systems

## 1. Introduction

It is expected that the building sector will contribute to 30% of global $CO_2$ emissions and consume 40% of the total energy by 2030 [1], leading to a significant global impact. The “Clean Energy for All Europeans” package [2] sets energy policies for 2030, with buildings playing a crucial role in Europe’s transition to clean energy. Cutting energy demand and boosting efficiency in buildings [3] and industries [4] through energy-saving programs is an effective way to mitigate the impact of fossil-based resources. The “energy efficiency first” principle [5] calls for taking the utmost account of cost-efficient energy efficiency measures in shaping energy policy and making relevant investment decisions. The Renewable Energy Directive [6] and Energy Performance of Buildings Directive (EPBD) [7] promote, among other aspects, on-site renewable energy generation and self-consumption in EU countries.

The motivation behind the advancement of green technologies is the desire to diminish the environmental consequences and alleviate the increasing costs associated with electricity. In this context, photovoltaic (PV) systems are the most popular solutions among the most favored technologies due to their ability to generate small-scale electricity and easy integration into buildings [8]. End-users equipped with PV systems connected to the grid can generate electricity for self-consumption and sell the generation surplus to other buildings or the grid [9]. Energy distribution losses are reduced by generating electricity at the point of use [10] and the advances in technology have decreased the cost of PV panels, making them more attractive for building use [11]. However, integrating solar energy into buildings is challenging due to its variability [12]. Solar energy is only available during the daytime and is affected by climate, location, season, and time [13]. Therefore, the increasing integration of variable and intermittent renewables can cause a mismatch between supply and demand, disrupting power system stability, efficiency, quality, and reliability [14][15][16].

## 2. The Evolution of Energy in Buildings

To better understand the efforts to reduce energy consumption in buildings, a brief overview of the evolution of energy in buildings is presented in **Figure 1**. The building sector has undergone a significant transformation, starting with a passive approach to reducing energy consumption using passive solutions [17]. Then, nearly zero-energy buildings (nZEBs) were developed to balance energy demand and renewable generation through on-site RES production [18]. Later, the concept of energy-flexible buildings was introduced by the IEA EBC Annex 67 [19], enabling buildings to manage energy generation and demand based on factors such as weather conditions, user needs, and grid requirements. The latest phase of this evolution is smart buildings, which participate in the energy infrastructure, acting as both energy sellers and buyers [20].

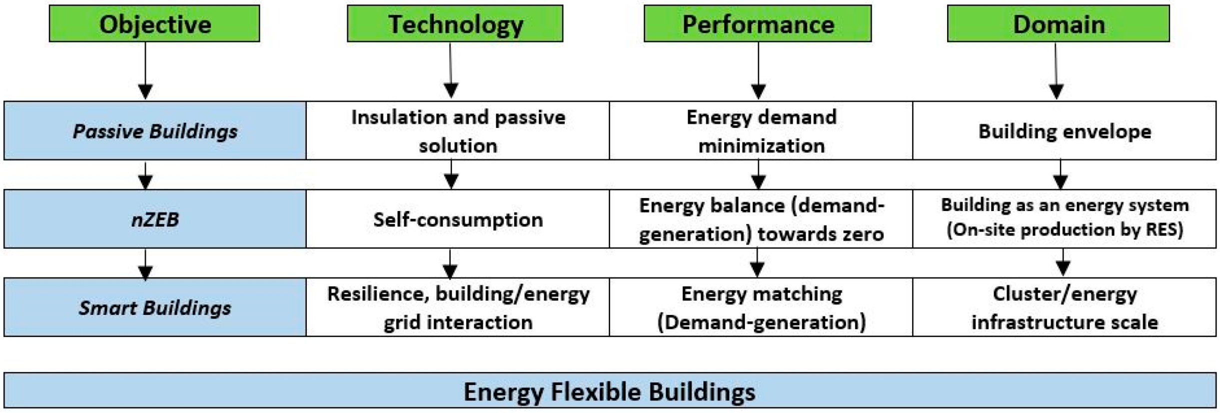


**Figure 1.** The evolution of buildings over time.

Integrating buildings into communities through the exchange of renewable generation surplus is a suitable solution to tackle the technical and economic challenges of energy management. The concept of a renewable energy community is defined in both the "Directive on the Promotion of the Use of Energy from Renewable Sources" [6] and the "Directive on Common Rules for the Internal Electricity Market" [21]. It must be emphasized that a building's energy demand is variable, and the worst case is when several customers' peak consumption occurs simultaneously, especially if this occurs during a period of low renewable energy generation availability. This issue is a serious challenge to the balance of renewable supply and demand. Energy systems require flexibility to align with the varying energy demand over time, a necessity particularly emphasized in electric energy systems, where demand and supply must be matched at every moment [22]. Therefore, energy storage systems (ESS) and demand response (DR) play crucial roles in providing the needed flexibility to ensure the matching between renewable generation and demand [23][24]. The integration of PV and ESS systems into a community of buildings helps to ensure that end-users can use energy locally produced according to their needs while minimizing the negative impacts on the reliability of the grid [25]. The cost of static batteries has been high in the past decades, which is one of the reasons for batteries not being already widely used in the building sector. Fortunately, the cost of batteries has been decreasing due to technological advancements and is expected to trend downwards [26].

Moreover, electric vehicles (EVs) complement static batteries with their flexibility. With vehicle-to-building (V2B) systems, EV batteries' excess capacity can supply energy to buildings [27]. EV batteries traditionally charge off-peak, or when energy is being produced locally, and provide energy during peak periods or later in the day when no local generation is available [28][29][30]. As relevant demand-side consumers, building communities can apply DR to optimize local generation integration and utilize energy storage systems [31]. In this context, shiftable loads also play a critical role in DR programs by allowing them to reduce peak demand [32]. Shiftable loads refer to electrical devices or appliances that can be scheduled to operate during periods of lower energy demand or when energy is more abundant and less expensive. Several loads in buildings are flexible, and their usage periods or cycles can be changed without affecting the comfort required by the occupants [33]. DR can be implemented via time-based and incentive-based programs [34].

In addition, building energy management systems (BEMS) play a critical role concerning energy management in the building sector and can be used to monitor and control energy demand [35]. Advanced energy management technologies, like BEMS, improve reliability and lower energy costs in buildings. BEMS can be used to optimize the matching between local energy generation and consumption and to reduce costs without sacrificing residents' comfort in smart buildings [36][37]. In a literature review, Shareef et al. [38] analyzed the use of artificial intelligence (AI)-based controllers, such as artificial neural networks (ANN), fuzzy logic control, and adaptive neural fuzzy inference systems, in home energy management systems (HEMS) based on DR and intelligent controllers, discussing the strengths and weaknesses of each. Addressing the complexity of data is a common challenge for BEMS to ensure effective functionality. However, using the Internet of Energy (IoE) for the transfer of energy data at the required time and place, with applications in electricity distribution, network monitoring, communication, and ESS, can significantly reduce these issues [39][40].

Additionally, the Internet of Things (IoT), which connects new sensing and communication technologies to anything from anywhere at any time, is widely used in intelligent buildings [41][42][43] and can have a significant impact on reducing energy consumption when adequately integrated into BEMS systems [44]. In addition, the smart readiness indicator (SRI), proposed to rate buildings based on their ability to adapt operations to residents' requirements, optimize energy efficiency, ensure overall performance, and respond appropriately to grid signals [45] plays a vital role in this context [46][47]. According to the Energy Performance of Buildings Directive (EPBD), buildings with a high SRI actively contribute to an intelligent energy system [48].

## 3. Energy Optimization in Buildings

Energy optimization plays a critical role in the building sector, being the main goal to minimize the energy consumption and energy costs of buildings while still providing comfort for the occupants [49]. Nowadays, energy optimization can have complex objectives, and the use of decision-making models and tools plays a crucial role. Operational research (OR) models and methods, such as multicriteria analysis (MCA), used to analyze possible alternatives and preferences and evaluate them under different criteria, and multi-objective optimization (MOO), which deals with optimizing solutions that satisfy multiple objectives, are effective in the energy sector for decision-making [50][51]. A system that considers technical, environmental, and economic factors is necessary for energy management, and the decisions should encompass sometimes conflicting objectives [52][53]. The importance of considering energy management is highlighted by A. Kumar et al. [54], and decision-making is critical when decisions have to be made based on several contradictory indicators [55].

In such a context, MCA involves evaluating multiple objectives and criteria to determine preferences among options in decision-making [56]. Despite MCA's strengths in structuring and framing complex issues, it has some weaknesses in achieving optimal decisions and solutions [57]. For instance, in numerous applications of MCA, the selection of objectives and criteria often neglects proper consideration of the geographical and temporal aspects of the analysis [58]. Furthermore, MCA-based methods do not provide the designer with information on how sensitive each criterion is to changes in the other criteria. The literature shows a gap between theory and practice in MCA's application [57]. MOO is important because it can model real-world problems with multiple conflicting objectives [59][60]. To address the various challenges in the building energy sector, energy optimization applying MOO is essential to meet users' needs while also reducing technical issues and energy usage in the building energy sector.

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