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Smart buildings as urban energy infrastructure: A scalable, privacy-aware framework for city-scale flexibility and resilience

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Abstract-

The transition toward sustainable and resilient cities increasingly relies on the large-scale deployment of smart buildings capable of actively interacting with urban energy systems. These buildings provide significant demand-side flexibility that can support efficiency, reliability, and resilience at the city scale if effectively coordinated. This paper proposes a decentralized coordination framework that integrates smart-building flexibility across interconnected urban layers, including buildings, microgrids, distribution networks, and the transmission grid. The framework enables market-based, time-dependent flexibility trading while preserving data privacy, a critical requirement for scalable smart-city applications. At the building level, smart buildings determine feasible flexibility ranges using a robust optimization model that accounts for uncertainty and comfort constraints. These resources are aggregated by Microgrid Operators (MGOs) and coordinated through local flexibility markets, with higher-level coordination managed by Distribution System Operators (DSOs) and the Transmission System Operator (TSO) to balance flexibility across interconnected urban layers. The proposed approach is implemented in GAMS and solved using CPLEX, and evaluated on a large-scale urban case study involving over 3300 smart buildings, 17 microgrids, four distribution networks, and a 30-bus transmission system. Results demonstrate notable sustainability benefits, including operational cost reductions of 33.86% for microgrids, 28.09% for distribution networks, and 6.76% at the transmission level, as well as a 17.26% reduction in system losses and improved voltage profiles. These findings underscore the pivotal role of smart buildings as active agents in urban energy management and highlight a scalable pathway toward more resilient and sustainable smart cities.

Index Terms- Smart buildings; Sustainable cities; Demand-side flexibility; Urban energy systems; Electric vehicle fleets; Energy resilience

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