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Comparative Analysis of Simulation-Based and Mixed-Integer Linear Programming Approaches for Optimizing Building Modernization Pathways Towards Decarbonization

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Abstract : The decarbonization of building stocks necessitates the modernization of existing buildings. Key measures for this include reducing energy demands through insulation of the building envelope, replacing heat generators, and installing solar systems. Given limited financial resources, it is impractical to modernize all buildings in a portfolio simultaneously; instead, prioritization of buildings and modernization measures for a given planning horizon is essential. Optimization models for modernization pathways can assist portfolio managers in this prioritization. However, modeling and solving these large-scale optimization problems, often represented as mixed-integer problems (MIP), necessitates simplifying the operation of building energy systems particularly with respect to system dynamics and transient behavior. This raises the question of which level of simplification remains sufficient to accurately account for realistic costs and emissions of building energy systems, ensuring a fair comparison of different modernization measures. This study addresses this issue by comparing a two-stage simulation-based optimization approach with a single-stage mathematical optimization in a mixed-integer linear programming (MILP) formulation. The simulation-based approach serves as a benchmark for realistic energy system operation but requires a restriction of the solution space to discrete choices of modernization measures, such as the sizing of heating systems. After calculating the operation of different energy systems in terms of the resulting final energy demands in simulation models on a first stage, the results serve as input for a second stage MILP optimization, where the design of each building in the portfolio is optimized. In contrast to the simulation-based approach, the MILP-based approach can capture a broader variety of modernization measures due to the efficiency of MILP solvers but necessitates simplifying the building energy system operation. Both approaches are employed to determine the cost-optimal design and dimensioning of several buildings in a portfolio to meet climate targets within limited yearly budgets, resulting in a modernization pathway for the entire portfolio. The comparison reveals that the MILP formulation successfully captures design decisions of building energy systems, such as the selection of heating systems and the modernization of building envelopes. However, the results regarding the optimal dimensioning of heating technologies differ from the results of the two-stage simulation-based approach, as the MILP model tends to overestimate operational efficiency, highlighting the limitations of the MILP approach.

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