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Using cooperative control to manage uncertainties for Aquifer Thermal Energy Storage (ATES)

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Aquifer Thermal Energy Storage (ATES) technology can lead to major reductions in energy demand for heating and cooling in buildings. ATES systems rely on shallow aquifers to seasonally store thermal energy and have become popular in the Netherlands, where a combination of easily accessible aquifers and strict energy regulations makes the technology especially relevant. However, this rapid adoption has made their management in dense urban areas more challenging. For instance, thermal interferences between neighboring systems can degrade storage efficiency. Policies for the permitting and spatial layout of ATES thus tend to be conservative to ensure the performance of individual systems, but this limits the space available for new systems – leading to a trade-off between individual system performance, and the overall energy savings obtained from ATES in a given area. Furthermore, recent studies show that operational uncertainties contribute to poor outcomes under current planning practices; systems in the Netherlands typically use less than half of their permitted water volume. This further reduces energy savings compared to expectations and also leads to an over-allocation of subsurface space.

In this context, this work investigates the potential of a more flexible approach for ATES planning and operation, under which neighboring systems coordinate their operation. This is illustrated with a three-building idealized case, using a model predictive control approach for two control schemes: a decoupled formulation, and a centralized scheme that aims to avoid interferences between neighboring systems (assuming perfect information exchange). These control schemes are compared across a range of scenarios for spatial layout, building energy demand, and climate, using a coupled agent-based/geohydrological simulation.

The simulation indicates that centralized operation could significantly improve the spatial layout efficiency of ATES systems, by allowing systems to be placed more densely without penalizing their individual performance. This effectively relaxes the trade-off between individual system performance and collective energy savings as observed in the decoupled case. The continued adoption of ATES technology provides a window of opportunity to revisit existing practices for the layout and operation of urban ATES systems, as information exchange – supported by appropriate spatial planning – could offer significant potential towards improved performance under operational uncertainties.