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Heterogeneity-Aware Building Stock Modelling for Urban Energy Transitions

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Academic dissertation

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Abstract

Bottom-up building stock modelling (BBSM) approach is widely used to assess the energy performance of urban building stocks by modelling individual buildings in detail and aggregating them to larger spatial scales. It plays an important role in supporting urban energy transition planning and policymaking. However, existing BBSM studies are constrained by several limitations, including incomplete building performance datasets, reliance on archetype-based averages in retrofit prioritization, simplified representations of occupant behaviour and building properties, and limited integration of modelling into public engagement tools. These limitations obscure inherent heterogeneity that determines which buildings benefit most from specific measures, leading to one-size-fits-all retrofit strategies and biased estimation of energy-saving potentials and policy effectiveness of energy transition initiatives.

This thesis advances heterogeneity-aware BBSM through an integrated and cumulative methodological pipeline that fuses incomplete building-performance datasets, enables localized retrofit prioritisation, and supports evaluation and communication of demand-side behavioural impacts. First, a data-fusion framework combines multiple incomplete datasets using probabilistic record linkage and inverse modelling, filling data gaps by transferring information across sources rather than relying on archetype-level averages. This improves stock representation by capturing building-to-building variation within the same urban context. Second, the thesis integrates data fusion with ensemble machine learning and explainable AI (SHAP) to identify impactful envelope retrofit measures in a local, data-driven manner. Across 81 building-stock clusters in three Swedish municipalities, the results demonstrate substantial variation in the most influential thermal components across municipalities and climate zones, underscoring the need for local-specific retrofit prioritisation. Third, the thesis incorporates occupant-behaviour diversity alongside building heterogeneity via an enhanced DOB-HUBS framework based on representative clustering, automated physics-based simulations, and surrogate machine learning. Empirical results the Umeå building stock demonstrate that oversimplified behavioural and homogeneous assumptions can bias energy outcomes by up to 15% (standard deviation 3.06%). The framework is further used to assess Sweden's forthcoming 2027 capacity-based electricity tariff, indicating that behavioural adaptations could reduce peak electricity demand by 6–17%, with heterogeneous impacts across clusters.

Building on these modelling advances, the thesis extends toward public engagement by developing data-driven benchmarking and interactive visual analytics platform that translate bottom-up modelling outputs into user-facing insights, including peer comparison and 'what-if' exploration of retrofit and behavioural scenarios. Collectively, the thesis contributes methods and empirical evidence for more credible, locally tailored, and publicly actionable building-stock analytics. This supports in designing targeted retrofit strategies, effective behavioural measures, and informed public participation in urban energy transition planning.

Keywords: Urban energy transition, building stock, bottom-up, heterogeneity, tailored retrofitting, public engagement, machine learning

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