IMPACT OF ELECTRICITY PRICE AND GRID TARIFF ON HEAT-PUMP-BASED FLEXIBILITY IN RESIDENTIAL BUILDINGS

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Introduction

The ongoing transformation of energy systems, characterized by rising shares of variable renewable energy, sector coupling, and electrification of building heating and cooling, substantially increases the need for flexible and responsive demand. Flexibility helps maintain system stability, reduce costs, and support reliable and resilient grids. Traditionally supplied by conventional power plants, flexibility must increasingly come from distributed resources. Buildings have emerged as a promising flexibility provider. According to the IEA EBC Annex 67, energy-flexible buildings can actively adjust their demand and on-site generation in response to user needs and energy infrastructure requirements. Most commonly, this involves shifting thermal loads using HVAC systems, often by exploiting the thermal mass of buildings as short-term energy storage [1]. This low-cost strategy enables peak shaving, load shifting, and improved integration of renewables.

This study investigates how dynamic electricity prices and time-varying grid tariffs influence the cost-saving potential of building energy flexibility based on a simulation study. Using simple rule-based control and sector-coupled heat pumps, it is evaluated how residential buildings can leverage their thermal mass to reduce operating costs while providing flexibility to the broader energy system.

Method

The simulations are conducted using the automated building stock modelling tool SimuDis [2], which incorporates detailed physical archetype models implemented in IDA ICE. Two representative Austrian residential building types with efficient thermal envelopes–a single-family house and a multi-family house constructed after 2010–are studied. Both are equipped with underfloor heating and an air-to-water heat pump. For each building type, a reference case without flexibility is simulated alongside several flexibility scenarios that use the total electricity cost per kWh as the control signal.

Energy flexibility is implemented by adjusting the temperature setpoint of the building within a range of 21.5 and 22.5 °C. The rule-based controller increases the setpoint to 22.5 °C during hours with particularly low electricity costs (< 25th percentile of the day) to “charge” the building’s thermal mass and decreases the setpoint to 21.5 °C during high-cost periods (> 25th percentile of the day), thereby reducing electricity use when prices are less favorable. Setpoints are updated hourly, and comfort is preserved by enforcing the minimum temperature regardless of the price signal. The simulation period spans the heating season from 1 September 2024 to 1 June 2025. Figure 1 illustrates the variable temperature setpoint in response to the price signal and the resulting heat load for the single-family house under an exemplary scenario. The red and green shaded areas indicate the shift in heating demand relative to a reference scenario with a static temperature setpoint of 22 °C.

The price signal comprises the electricity price and the grid tariff, which are treated either dynamically or as fixed averages, depending on the scenario. The dynamic price is based on EXAA day-ahead spot market data [3]. Time-varying grid tariffs follow a three-level structure inspired by the German regulatory model [4], [5], distinguishing low-price nighttime hours (2.6 ct/kWh from 00:00-04:00), standard daytime periods (8.6 ct/kWh from 04:00-17:00 and 20:00-24:00), and a short high-price peak in the early evening (12.5 ct/kWh from 17:00-20:00). Fixed-price or fixed-tariff cases are represented by the average values for the simulation period.

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Results

The results in Figure 2 show that the cost-saving potential of energy flexibility depends strongly on the type of price and tariff signal. Scenarios that rely only on dynamic electricity prices deliver the lowest savings, while scenarios that include variable grid tariffs show higher savings. A structured signal considering variable grid tariffs allows the rule-based controller to shift load more effectively. The results demonstrate that even simple control strategies can benefit from well-designed tariff structures. Across scenarios F2 and F3, single-family houses achieve higher savings than multi-family houses. This is not the case for scenario F1, where the multi-family house achieves higher savings. In this scenario, the multi-family house further shows a larger reduction in the heat pump's electricity consumption than in its total electricity costs C_{el}. In other words, the flexible scenario uses less electricity overall, but the control strategy fails to shift consumption into low-price periods and therefore does not reduce the effective cost per kWh. Interestingly, the simulations also indicate an overall improvement in heat pump efficiency for the single-family house: electricity consumption decreases while the delivered heating energy increases, suggesting that the heat pump operates under more favorable conditions during preheating events.

The findings show that especially variable grid tariffs are a powerful driver for unlocking building energy flexibility. Even with a simple rule-based controller and a narrow comfort temperature range, residential buildings, especially single-family houses, can shift heating demand into more economical periods and achieve measurable cost reductions between 6.6-25.5 %.

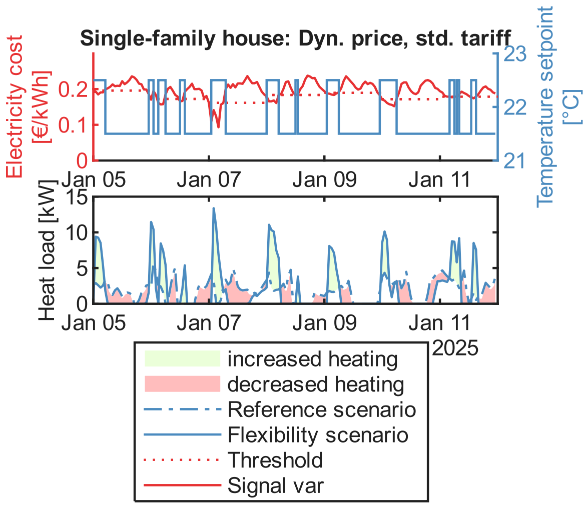

Figure 1: Variable temperature setpoint in response to the price signal and the resulting heat load for the single-family house in the flexibility scenario, compared to the reference scenario.

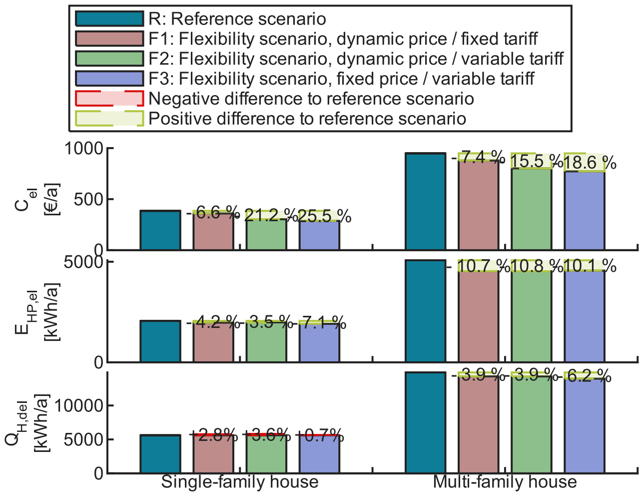

Figure 2: Total electricity cost C_{el}, electricity consumption $E_{HP,el}$ and heating energy delivered $Q_{H,del}$ for two building types and three energy flexibility scenarios

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