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], [2]. This low-cost strategy enables peak shaving, load shifting, and improved integration of renewables [3].

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 rely on the automated building stock modelling tool SimuDis [4], which incorporates detailed physical archetype models implemented in IDA ICE. Two representative Austrian residential building types with efficient thermal envelopes, namely a single-family house and a multi-family house constructed after 2010, are studied (see [5] for more details). Both are equipped with underfloor heating and an air-to-water heat pump. For each building type, we simulate a reference case without flexibility as well as several flexibility scenarios that use the total electricity cost per kWh as the control signal. This total cost combines the electricity price and the grid tariff, which are treated either dynamically or as fixed averages depending on the scenario.

The dynamic price input is based on EXAA day-ahead spot market data [6], which is published in advance by the Austrian Power Grid and thus suitable for rule-based control. Time-varying grid tariffs follow a three-level structure inspired by the German regulatory model [7], [8], 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.

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.

Results

The results in Figure 1 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. The short-term volatility of spot market prices causes frequent changes in the temperature

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setpoint, leading to many heat pump on-off cycles. In contrast, scenarios that include variable grid tariffs show clearly higher savings because the tariff schedule creates predictable low-cost windows during which the building can reliably preheat. This structured signal allows the rule-based controller to shift load more effectively, demonstrating 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. While this is also the case in scenario F1, the multi-family house 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 reveal that an overall improvement in efficiency of the heat pump can be achieved, 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.

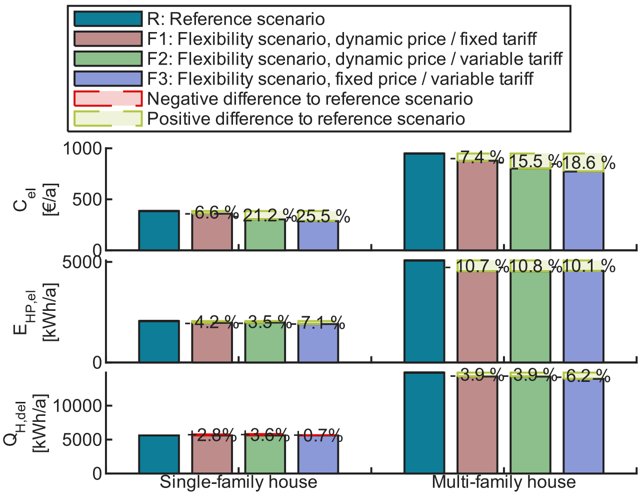

Figure 1: Total electricity cost C_{el} , Electricity consumption $E_{HP,el}$ and heating energy delivered for two building types and three energy flexibility scenarios

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