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SIMULATION-BASED HEAT PUMP SYSTEM PERFORMANCE OPTIMISATION OF LARGE APARTMENT BUILDINGS AND DISTRICTS

Summary

A systemic simulation-based planning approach for district energy systems includes the total heat demand, network length and layout, heat line density, local heat source availability, climate conditions, and renewable energy potential. Cost-optimal solutions need to be identified considering highly efficient thermal envelopes, very efficient heat pump (HP)-based heat generation combined with low-temperature heat distribution systems as well as maximized photovoltaic yield. Decentralized or semi-centralized HP system concept with reduced distribution losses enable higher seasonal performance. Cold district heating or medium-temperature semi-central systems that combine central heat pumps with decentralized booster units for domestic hot water (DHW) preparation can be a promising alternative to classical high temperature district heating system. HP system topology is a key determinant of system efficiency. Simulation models and methods are required that are able to simulated large buildings and districts with the required level of detail and allowing high simulation performance.

Keywords: Positive Energy District, Efficiency, Heat Pump System, Monitoring, Simulation,

Field of application for the findings: Transition to Renewable and CO_2-Free Energy System

Addressed audience: Science, Planner, Decision Maker

1. Introduction

In order to foster the transition of the European building stock, the concept of positive energy districts (PED) has been defined and energy-efficiency, on-site renewable energy generation and energy-flexibility on urban scale shall be demonstrated (Lindholm et al. 2021). PEDs are defined as groups of interconnected buildings that have no net greenhouse gas emissions and actively manage an annual local or regional surplus of renewable energy (Hedman et al. 2021). Besides the high-quality thermal envelope of the buildings, prerequisite for achieving a positive energy balance is a very efficient heating (and cooling) system. The heat pump (HP) system topology is one of the main drivers for system efficiency (Ochs et al. 2026).

The housing project “Innsbruck Campagne” with approx. 78 000 m² developed in four blocks of each four buildings is used as a case study for simulation-supported integral planning of HP-based heating (and cooling) systems for PEDs. The first block, comprising four apartment buildings following the Passive House standard with a total of 307 apartments and 2 500 m² of commercial space, has been, see Fig. 1, and since 2023 intensive energetic monitoring is carried. All buildings have a heating demand (HD) close to 15 kWh/(m² a) and correspondingly a very low heating load (HL) in the below 15 W/m², see Tab. 1. A ground-water HP supplies low temperature heat to the floor heating system and the local district heating system supplies heat to the decentral flat-wise fresh water stations (FWS).

Table 1: Treated area (A_T), heating demand (HD) and heating load (HL) for the four buildings: A, B, C, D (Ochs et al. 2026)

	A	B	C	D
A_T / [m²]	6686	6525	3587	5479
HD / [kWh/(m² a)]	15.3	15.0	20.0	16.0
HL / [W/m²]	11.9	11.5	15.1	12.8

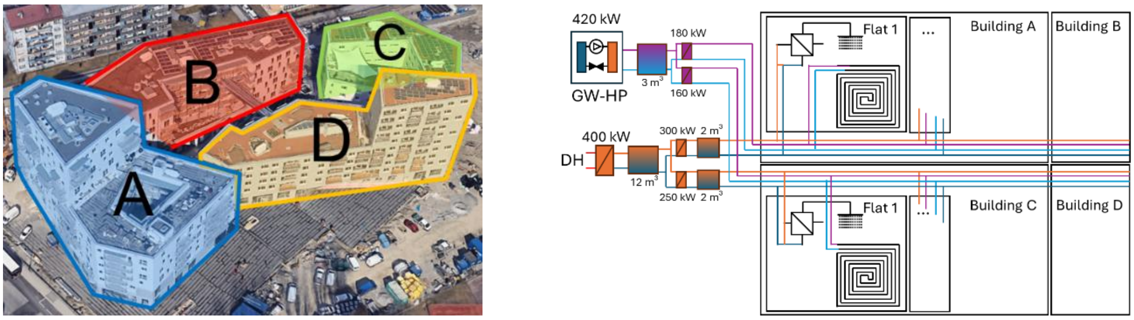


Fig. 1: Block 1 of Campagne areal with the four buildings A, B, C, D in Innsbruck (left, google earth) and heating system (right) with ground water (GW) HP for SH and district heating (DH) for DHW.

2. Method

2.1 Monitoring

DHW demand is monitored in detail in each of the 50 flats of building C (on the primary side of the FWS). Load patterns are analyzed and distribution losses can be determined as a difference between the heat meter in the heating central, in each building and in building C the sum of all flats. The simultaneity factor is used to determine the required sizing of components in the capacity of the HP and other equipment such as volume of the buffer and size of heat exchanger. Acc. to VDI 2072 the simultaneity factor is a function of the number of flats (eq. 1):

$$\varphi_{VDI} = 0.03 + 0.5 \cdot n_{flat}^{-0.5} + \frac{0.47}{n_{flat}} \qquad \text{(eq. 1)}$$

2.2 Simulation

The simulation model focuses on the heat distribution from the buffer to the flats. The (cost-)optimal HP integration options depend on the distribution system, number and size of buffer storage and the useful energy (SH + DHW). The system performance depends on both, the distribution losses and the flow and return temperatures. The accurate prediction of the distribution losses and return temperature requires simulation models and tapping profiles on flat level (Venturi et al. 2026). They depend on the size and geometry of the building as well as location of or distance between the buildings, respectively (i.e., length and thermal quality of the distribution pipes). Furthermore, the HP system topology with the corresponding temperature levels has a significant influence. For large buildings and districts with some hundred flats, this is a challenge and computational effort is very high. Reduced order models are required.

3. Results

3.1 Monitoring

DHW tapping patterns from the detailed monitoring of 50 flats of building C and of the delivered energy measured in the heating central are shown in Fig. 2. In both figures a peak between ca. 16:00 h and 22:00 h can be observed (and also the shift of 1 h resulting from winter and summer time). It can be also observed, that the peak in the evening is much more pronounced than the one in the morning (staring around 05:00 h) In addition, a relative strong seasonal effect can be observed in case of the delivered energy with pronounced energy delivery in the winter months.

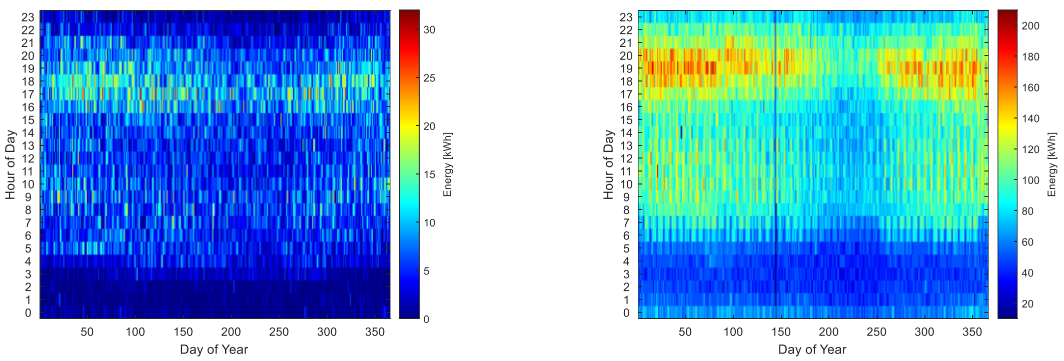
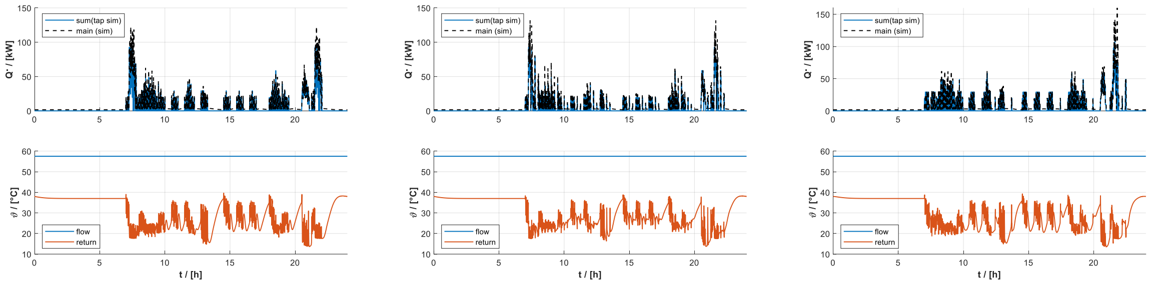


Fig. 2: Carpet plot of 2024 of the DHW tapping measured in the flats (i.e., sum of 50 flats of building C, left) and delivered energy in the heating central for all for buildings (right)

3.2 Simulation

Fig. 3 shows simulation results of the heating power required for the decentral DHW preparation with FWS (measured at the buffer outlet) and the resulting central return temperature for the example of four parallel staircases with each 5 flats. Three cases are compared a) using time-shifted tapping profiles acc. to EN 16147 M corresponding to 4 persons per flat (left hand side) b) reduced profile accounting for 3 persons per flat (center) and c) a modified profile that includes only 1 shower in the evening (right hand side). The peak power and correspondingly simultaneity factor measured at the central distribution (main) depends on the profile as well as on the flow temperature.



$Q_{main} = 196.0\ kWh$	$Q_{main} = 167.9\ kWh$	$Q_{main} = 166.4\ kWh$
$Q = 174.8\ kWh$	$Q = 146.6\ kWh$	$Q = 145.4\ kWh$
$\varphi_{sim} = 0.25$	$\varphi_{sim} = 0.27$	$\varphi_{sim} = 0.33$

Fig. 3: Flat level simulation model (example of 4 x 5 flats) with decentral FWSs and time-shifted profiles based on EN 16147 M to match simultaneity acc. to VDI 2072 (eq. 1), left reference (w/ two showers: 4 persons), center reduced to account for 3 persons per flat and right modified with only shower in the evening corresponding to 3 persons per flat

4. Conclusions and Outlook

The paper presents based on monitoring results from the "towards" PED Innsbruck Campagne simulation methods and results. The accurate prediction of the heating load (SH and DHW) as well as of the required flow and resulting return temperature is the basis for simulation-based optimization of positive energy buildings and positive energy districts. The possible reduction of the flow temperature or the increase of the return temperature due to faults in one or several FWS bypass is investigated as a possible application of a digital twin. However, as the simulation time increases potentially with increasing number of flats, reduced order models are required for modelling large buildings or districts. These ROM can be derived from the detailed models.

5. References

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