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Decentral heat pumps for the retrofit of apartments

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Abstract

The replacement of decentral gas boilers, common in many European countries, is a key challenge on the pathway to the decarbonization of building stock. The solution proposed in this work is the stepwise retrofitting of multi-family houses formerly using decentralized gas boilers, using a semi-central system with decentral apartment heat pumps in the dwellings. Building on promising simulation results from a research project, demonstration in a real building has shown that a semi-central heating system can avoid distribution losses, stop worst-case design, and enable an incremental retrofit, offering a wide range of applications. Within a research project, a small-scale R290 heat pump for apartment-wise deployment has been developed based on requirements explored in a serially retrofitted multi-family house (MFH). In a second use-case, a semi-central heat pump system has been already implemented. First measurement results show a good adaption to different supply temperature levels and a good overall system coefficient of performance (SysCOP).

Keywords: apartment heat pump; decentral heat pump; multi-family house; retrofit; decentralized heating; booster heat pump; R290

1. Introduction

Heat pumps (HPs) have long been established as an efficient technology for space heating (SH) and domestic hot water (DHW) preparation. Nevertheless, their adoption in urban areas remains limited. In Austria, 14 % of primary residences are heated by solar and heat pumps, while in the capital Vienna, these are only 2 % [1]. General reasons for the hesitant use of heat pumps in urban zones with a high share of multi-family houses (MFHs) can be acoustic constraints, space constraints, heat source availability, invest, as well as complicated ownership and rent structure.

In recent years, dedicated HP system solutions for multi-family houses and renovation projects have been developed [2]. A major challenge in such applications is the relatively high temperature required for DHW preparation, which causes significant distribution losses and reduces the efficiency of central HP systems [3].

Each heat pump concept comes with its own set of challenges. Brine-to-water (B2W) or water-to-water (W2W) systems require heat sources such as borehole heat exchangers, which are often not feasible due to space constraints. Air-to-water (A2W) heat pumps need high air flow rates and are therefore typically installed outdoors—a trend strengthened by the shift to natural, flammable refrigerants. Yet, outdoor installation is often limited by noise protection regulations [4]. Decentralized HP configurations, on the other hand, face limitations regarding suitable heat sources and installation space [5].

In the context of both existing district heating (DH) networks [6] and emerging 5th generation district heating systems (5GDH) [7] booster HPs (providing high temperatures based on medium temperature distribution) have increasingly gained attention as a promising option. Accordingly, various booster HP system concepts have been proposed, and several decentralized configurations have been developed in recent years. For instance, return-flow HPs for flat-wise DHW preparation were analysed through simulations by [8], showing that the achievable efficiency improvement compared to central DHW preparation strongly depends on the building's thermal performance. A detailed investigation of such a return-flow HP in a multi-apartment building and its influence on the PV self-consumption was presented in [9]. A field application combining a booster HP with a central ground-source HP was demonstrated in [10].

Booster HPs for DHW supply in ultra-low-temperature DH networks were examined in [11], and a corresponding prototype was developed in [12]. For such applications, [13] optimized the integration of booster HPs. Flat-wise booster HPs and their DH system-level impact on DH networks were studied in [2]. Another variant was proposed by [14], applying a booster HP for DHW circulation in central systems; this concept was later advanced into a future-proof substation design by [15]. The potential of semi-central HP system solutions with booster HPs for renovation projects was demonstrated by [16], while [17] compared various HP concepts including booster HPs at building and block levels.

The contributions of this work are (i) the development of an R290-based apartment heat pump with improved placement and dimensions to fit also small apartments, yet providing sufficient capacity to cover for both DHW and SH, which was not the case in any of the mentioned studies, and (ii) to showcase a two-stage heat pump concept using a central A2W HP, low-temperature distribution and decentral apartment heat pumps for DHW and SH.

2. Methodology

2.1. Investigation of special challenges for decentralized heat pump systems in two use-cases

In two separate case studies, the authors of this work investigated the possibility, advantages and imposed challenges of replacing a gas combi boiler with a decentral heat pump system. Use-case A is a set of seven similar MFHs with six apartments of a size of 60.5 m² each on three floors. The heating systems inside the dwellings were diverse, reaching from electric night storage heaters to gas combi boilers. There was no central heat distribution system. Within the Austrian research project PhaseOut, three different heating systems were elaborated: Centralized heating and DHW preparation using A2W heat pumps, centralized heating and decentralized DHW preparation by A2W heat pumps and direct electric boilers, and a semi-central system using a central A2W heat pump and decentral W2W booster heat pumps. The aim was to reach the highest possible system efficiency, considering not only the efficiency of the heat pumps, but also the distribution losses within the building.

Use-case B is a MFH in Vienna consisting of dwellings between 45 m² and 85 m², making up an effective area of around 1000 m². The dwellings are diverse, some to be equipped with floor heating, some not. At the beginning of the project, some dwellings were rented out, some were empty, some were even rented out via short-term vacation rental. The aim of this use-case was to showcase a serial retrofit (still ongoing), equipping one apartment after another and getting by with the least possible centralized heating technology. The source concept should be gradually extendable, starting with A2W heat pumps, supported by photovoltaic-thermal (PVT) panels, and being able to change to a ground source concept or low-temperature district heating later.

For both these use cases, challenges were analysed, requirements for a decentral heat pump were derived, and a small-scale apartment heat pump prototype that satisfies the requirements was developed. Further, different system concepts were elaborated, and a semi-central concept with a central A2W heat pump, low-temperature distribution, and decentral W2W booster heat pumps was implemented in use-case B.

2.2. Interpretation and comparison of measurement results

The implemented use-case B was provided with monitoring equipment, and measurements have been already conducted. Each decentral heat pump as well as the central heat pumps are equipped with a flow sensor (measurement accuracy of ±2 %) and temperature measurement (typical uncertainties of ±3 %) on supply and return flow, which enables a reliable measurement of heat flows. The heat pumps' compressor's electric power consumption is measured at the inverter supply (measurement accuracy of ±5 %). The measurements in use-case B are presented in section 4.3. Based on the measurements collected over two weeks in autumn (will be extended), a SysCOP was calculated according to equation (1), with $E_{el,hp,cent}$ being the electric energy consumption of the central HP, $E_{el,hp,d}$ and $Q_{hp,d}$ being the electric energy consumption respectively dissipated heat of each apartment HP $d \in [1|9]$.

$$SysCOP = \frac{\sum_{d \in D} Q_{hp,d}}{\sum_{d \in D} E_{el,hp,d} + E_{el,hp,cent}}, D = [1|9] \quad (1)$$

Due to the complexity of the system, where decentralized apartment heat pumps use heat from the intermediate-temperature network for both space heating and domestic hot water preparation, the efficiency for space heating and hot water cannot be assessed separately. However, the share of emitted energy per system mode can be shown separately.

3. Explored requirements

3.1. Identification of requirements to a decentralized apartment heat pump

The requirements for heat pumps intended for the installation inside apartments are very tough regarding noise emissions, space, flexibility, and comfort.

In Austrian building standards, the maximum noise level is defined differently for rooms with different purposes [18]. For the sake of highest acceptable noise levels, secondary rooms like bathrooms and toilets were considered for the installation, where a sound power level of roundabout 43 dB should be acceptable. The availability of space in these but also in other rooms turned out to be extremely restricted.

As the dwellings in both use-cases were mostly rented out, all areas on the floor were taken by furniture or, especially in the bathroom, by white goods. When a gas boiler is exchanged, at least the space of the gas boiler is available, which is around 450x750x350 mm (WxHxD) [19]. The gross available space turned out to be a bit more, considering that an additional height of about 300mm is usually kept free for the exhaust pipe. Additionally, awkward space below the ceiling was usually kept free (cf. Figure 1). To fit all cases, a modular concept of heat pump and separate DHW store proved more flexible than a combined and thus bigger combination of both.

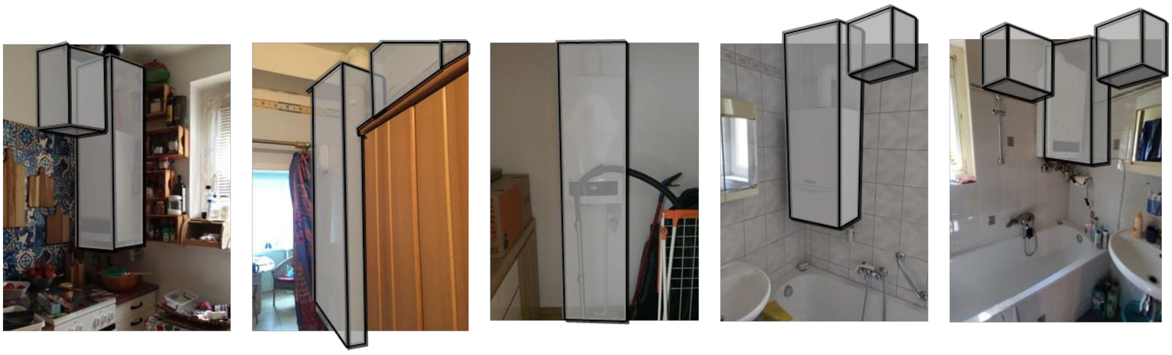

Figure 1: Empty spaces (including exchanged gas boilers) inside dwellings of use-case A. ©UIBK

From the need for serial retrofits arises the requirement for flexibility, not only regarding placement, but also thermal capacity and supply temperature. For different sizes of dwellings and different renovation stages, a modulation range from 1.5 to 4.5 kW was targeted. Table 1 summarizes the explored requirements.

Table 1: Requirements for a small-scale, widely applicable apartment heat pump

Requirement	Value	Comments
Size	max 800x450x450 mm WxHxD.	Height: usual room height minus height to be kept free from technical equipment; Depth: usual size of furniture: Width: usual minimum width of a toilet
Installation weight of heat pump	60 kg	Maximum for lifting over the head by two people.
Heat load covered	1.5 kW to 4.5 kW	At W0W35/W0W55
IP classification	IP X4	Bathroom installation
Installation time	1 day	Given prepared heat source
Natural refrigerant	R290	
Refrigerant charge	< 150 g	Due to safety standards EN60335, EN378
Heating technology included	Cold cycle, inverter, electronics, supply pump, three-way valve for DHW, non-return valve, overflow valve, heat meter	

4. Results

4.1. Development of a small-scale apartment heat pump

Based on the requirements from 3.1, a prototypic cold cycle was developed. For the sake of charge-reduction a minimal setup of a dual rotary compressor, two plate heat exchangers, an electronic expansion valve and a liquid line filter dryer was used. First tests showed promising results: At W10W35S50%, a COP of 5.70 at a capacity of 3.38 kW, and a maximum capacity at 100 % of 5.74 kW was achieved. High effort was then spent on the construction and packaging of components to allow downsizing the package to the required dimensions. For fast installation, the heat pump consists of three parts: A ceiling console including installation fittings, the heat pump itself hanged in the console, and the casing. Figure 2, left, shows one of the first applied prototypes. Figure 2, right, shows COP and thermal capacity curves for a preliminary SCOP test on the prototype.

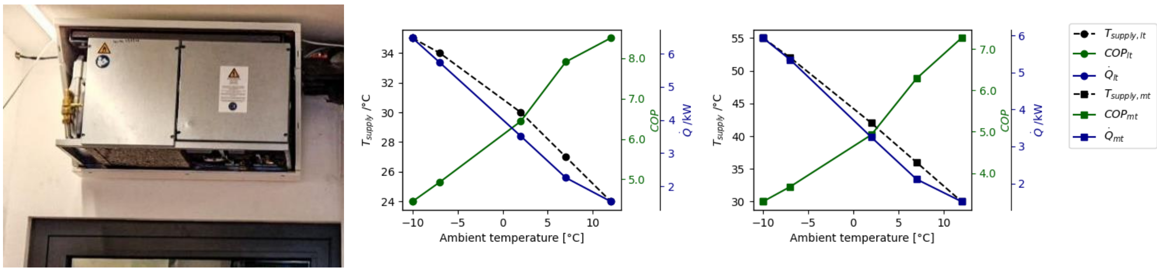

Figure 2: Installed prototype without housing (left), preliminary SCOP test results ($\dot{Q}, COP$) from the test bench for intermediate climate, low (lt) and medium temperature (mt) heating (right)

4.2. System concepts

Especially in urban zones, where the building density is high, finding a suitable heat source is a major challenge for any heat pump concept. A2W heat pumps are often not applicable due to their noise emission combined with tight legal regulations, geothermal heat pumps are often not applicable due to limited area for ground source heat exchangers. Moreover, the establishment of a ground heat source is most often connected to a high invest. A decentralized system should therefore be flexible and able to make use of what is available.

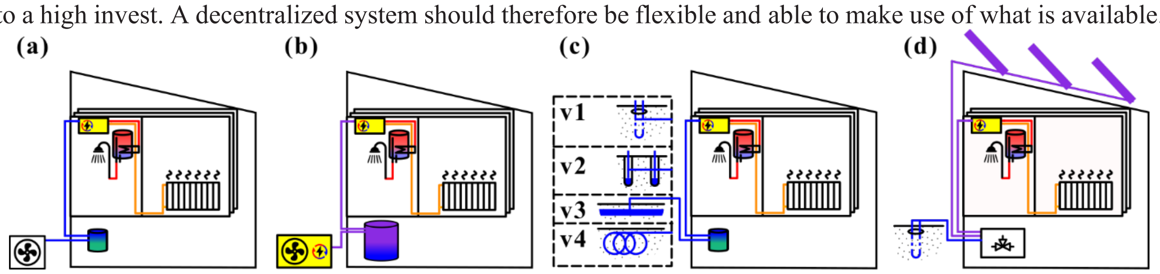

Figure 3: Elaborated system concepts for decentralized apartment heat pumps

Figure 3 shows four of the developed system concepts. In concept (a), the decentralized heat pumps are supplied by a central fan coil or other central heat exchangers. Photovoltaic-thermal panels (PVT) are one possible option. In concept (b), a central A2W heat pump feeds an intermediate temperature circuit, which then feeds the decentral heat pumps. In a simulation study, this concept proved to be the most system-efficient of different air-source systems, considering the close to zero storage and distribution losses [16]. In concept (c) the decentralized heat pumps are fed by a centralized ground source, in the four variants borehole heat exchanger, groundwater well, low-temperature district heating networks, and heat collector. Concept (d) combines an economically designed ground source heat exchanger with an air source (PVT) and an intelligent heat source management to always make use of the most efficient heat source, and to regenerate the ground source in summer. System concept (b) is being implemented in use-case A and has been preliminary implemented in use-case B, with the option to change for a bivalent source system (d) later.

4.3. Measurement results and comparison

In use-case B, measurements have been conducted. Measurement results for a week in transition period are shown in Figure 4.

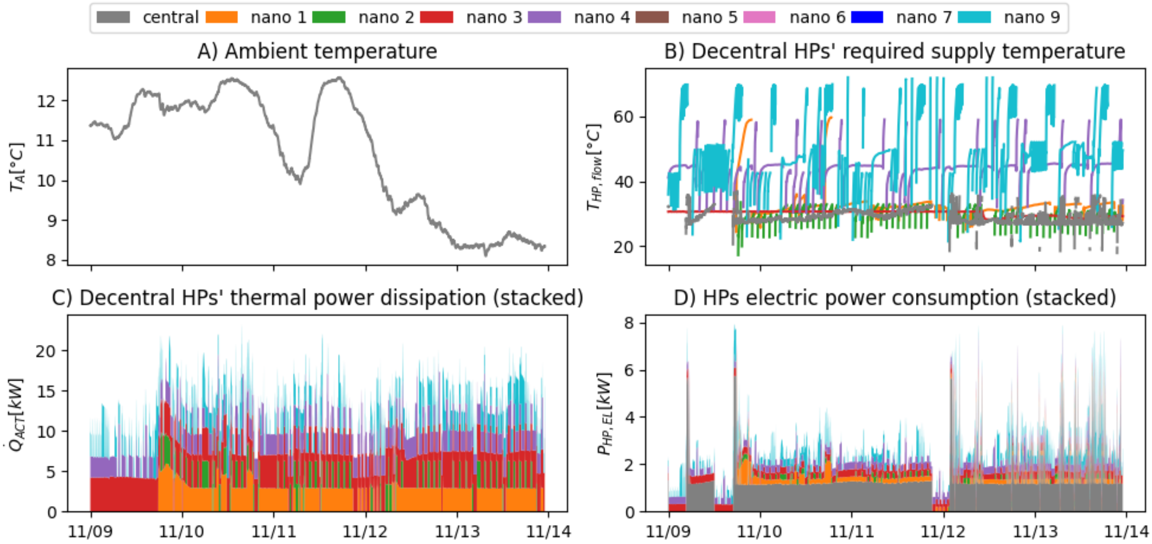

Figure 4: Excerpt of monitoring data: measured heat flow of central heat pump (up), decentral heat pumps (middle) and supply temperatures (including dhw production)

Figure 4, plot A) shows the ambient temperature over time. Plot B) shows the resulting supply temperature (in heating and DHW mode) for the equipped prototypes. The difference between supply temperatures in the different dwellings is remarkable, and results from differently adjusted heating curves or static supply temperatures. One advantage of the booster concept is evident from this plot: While the required supply temperature fluctuates, the central A2W heat pump always runs on a highly efficient intermediate temperature. Moreover, the low intermediate temperature of around 26 °C minimizes temperature losses in the buffer store and distribution piping. Plot C) shows the heat flows into the dwellings (stacked). The electric power consumptions of all decentral and the central heat pump can be seen in plot D).

Figure 5 details the latter two plots and shows the electric consumption of the two-stage system in comparison to the effective heat for space heating, respectively DHW preparation and summed energies per system mode and heat pump.

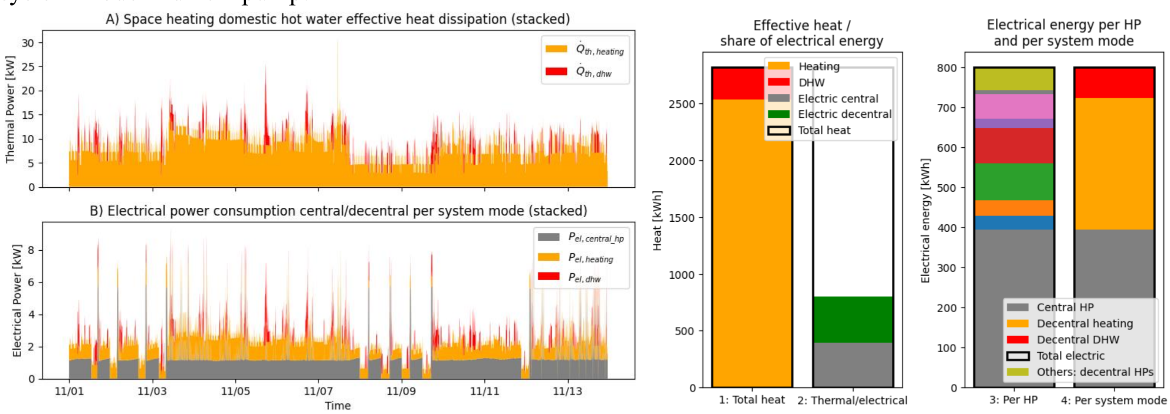

Figure 5: Comparison of electric consumption, powers over time (left) and total energies (right).

Figure 5, plot A), shows the thermal power dissipation for heating and DHW preparation separately. In plot B), the electrical power consumption is split up in decentral power consumption for space heating, decentral power consumption for DHW preparation, and power consumed by the central heat pump. It is obvious that the differences in required supply temperatures and heating loads lead to spikes in the decentral heat pumps, while the central heat pump doesn't have to follow these peak demands. The bar plots on the right show the heat dissipation per system mode (bar 1), the share of electricity in the thermal energy in central and decentral HPs (bar 2), the electricity consumption per heat pump (bar 3) and per system mode (bar 4). The system reaches a SysCOP (dissipated heat for space heating and DHW preparation divided by electric energy consumption of all heat pumps) of 3.52.

Conclusion and Outlook

This work demonstrates that decentralized apartment heat pumps combined with a semi-central system architecture offer an effective pathway for the gradual decarbonization of multi-family buildings with apartment-wise gas boilers. The developed R290-based heat pump meets the demanding requirements for installation inside dwellings regarding space, acoustics, safety, and flexibility. The demonstration in use-case B confirms that the two-stage system achieves high overall efficiency: the central air-to-water heat pump can operate continuously at a stable, low intermediate temperature, leading to low distribution losses, while the decentralized booster units flexibly cover individual heating and DHW demands at different temperature levels. This division of tasks reduces peak loads on the central unit, supports fair consumption-based billing, and allows stepwise renovation without major interventions in the building.

Overall, the results indicate that decentralized apartment heat pumps represent a scalable and future-proof solution for urban retrofit projects, enabling efficient operation today while remaining compatible with future low-temperature or geothermal heat sources. Further research will be done over the heating period to investigate system efficiencies at lower ambient temperatures. Moreover, use-case A is currently being implemented and will enable a direct comparison of central HP systems and semi-central booster concepts.

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References

[1] “Energieeinsatz der Haushalte.” STATISTIK AUSTRIA, May-2025.
[2] F. Ochs, M. Magni, and G. Dermentzis, “Integration of Heat Pumps in Buildings and District Heating Systems—Evaluation on a Building and Energy System Level,” *Energies*, vol. 15, no. 11, p. 3889, May 2022.
[3] F. Ochs, S. Breuss, E. Venturi, M. Magni, G. Dermentzis, and S. Fisco, “MODELLING AND SIMULATION OF INNOVATIVE DECENTRAL DOMESTIC HOT WATER SYSTEMS WITH HEAT PUMPS FOR MULTI-FAMILY BUILDINGS,” *Bausim 2020, Graz*, no. 2014, 2020.
[4] S. Greif, T. Limmer, and F. Mayer, “Potential of air-source heat pumps complying with sound immission limits in the German building stock,” in *ETG Congress 2021*, 2021, pp. 1–5.
[5] B. Nienborg, A. Uhl, B. Rodenbücher, and P. Engelmann, “Propane-based heat pump solutions for existing multi family houses - requirements and possible system solutions,” in *Proceedings of EuroSun 2024. ISES and IEA SHC15th International Conference on Solar Energy for Buildings and Industry*, 2024.
[6] P. A. Østergaard and A. N. Andersen, “Booster heat pumps and central heat pumps in district heating,” *Applied Energy*, vol. 184, pp. 1374–1388, Dec. 2016.
[7] L. M. Dang, L. Q. Nguyen, J. Nam, T. N. Nguyen, S. Lee, H. K. Song, and H. Moon, “Fifth generation district heating and cooling: A comprehensive survey,” *Energy Reports*, vol. 11. Elsevier Ltd, pp. 1723–1741, Jun-2024.
[8] F. Ochs, P. Krimbacher, D. Siegele, and W. Feist, “Niedertemperaturheizung in Kombination mit einer dezentralen Boiler-Wärmepumpe,” in *BauSIM*, 2014, pp. 379–386.
[9] M. Magni, F. Ochs, G. Dermentzis, and E. Venturi, “Modelling and Simulation of Booster Heat Pump for DHW Preparation in a Multi-Family Building Connected to the District Heating,” 2024, pp. 1–12.
[10] W. Boydens, S. Feyaerts, A. Vandermeulen, and L. Helsen, “Control strategy assessment of a small GSHP sourced DH system with end user DHW booster heat pumps,” in *IEA HPC 2024*, 2020.
[11] T. Zhu, T. Ommen, W. Meesenburg, J. E. Thorsen, and B. Elmegaard, “Steady state behavior of a booster heat pump for hot water supply in ultra-low temperature district heating network,” *Energy*, vol. 237, Dec. 2021.
[12] T. Zhu, Y. Du, J. Liang, W. Rohlfs, J. E. Thorsen, and B. Elmegaard, “Integration of booster heat pumps in ultra-low temperature district heating network: Prototype demonstration and refrigerant charge investigation,” *Energy and Buildings*, vol. 298, Nov. 2023.
[13] T. Ommen, J. E. Thorsen, W. B. Markussen, and B. Elmegaard, “Performance of ultra low temperature district heating systems with utility plant and booster heat pumps,” *Energy*, vol. 137, pp. 544–555, Oct. 2017.
[14] J. E. Thorsen, S. Svendsen, K. M. Smith, T. Ommen, and M. Skov, “Feasibility of a booster for DHW circulation in apartment buildings,” *Energy Reports*, vol. 7, pp. 311–318, Oct. 2021.
[15] Q. Yang, R. Salenbien, E. Motoasca, K. Smith, and M. Tunzi, “Development and test: Future-proof substation designs for the low-temperature operation of domestic hot water systems with a circulation loop,” *Energy and Buildings*, vol. 298, Nov. 2023.
[16] D. Jähnig, M. Male, and F. Ochs, “Sanierung mit Wärmepumpen in Mehrfamilienhäusern – eine Simulationsstudie,” in *Proceedings of ENOVA 2025*, 2025, p. 350.
[17] G. Dermentzis, F. Ochs, A. Thuer, and W. Streicher, “Supporting decision-making for heating and distribution systems in a new residential district - An Austrian case study,” *Energy*, vol. 224, p. 120141, Jun. 2021.
[18] *OIB-Richtlinie 5: Schallschutz*, no. OIB-330.5–002/19. Österreichisches Institut frür Bautechnik, 2019.
[19] B. Nienborg, A. Uhl, B. Rodenbücher, H. Fugmann, and P. Engelmann, “Outlining the requirements for propane-based heat pump solutions for existing multi family houses,” in *16th IIR-Gustav Lorentzen Conference on Natural Refrigerants, GL 2024. Proceedings*, 2024.