EARLY-STAGE TECHNO-ECONOMIC ANALYSIS OF RENOVATING MULTI-APARTMENT BUILDINGS WITH HEAT PUMP SYSTEMS

Summary

Heat pumps (HPs) reduce primary energy use compared to conventional fossil-based heating systems (such as gas boilers). However, for the application in multi-apartment buildings (MAB), selecting the most suitable, i.e. cost-optimal HP system is challenging because of the multi-dimensional design space. Optimal solutions depend on the project-specific boundary conditions and constraints as well as on the individual optimisation goals (e.g., minimum CO_2 emissions, minimum total annual cost or minimum investment cost). This work introduces an integral planning method including thermal envelope renovation, HP system topology and HP source as well as on-site PV. A sensitivity analysis is conducted including different MABs, thermal renovation levels, emission-, distribution-, and generation-systems as well as PV size. Using a spreadsheet-based approach, monthly energy demands, including PV self-consumption, are computed and monthly CO_2 factors are applied to account for seasonal variation of the electricity mix. In contrast to previous studies, this techno-economic analysis focuses in detail on the HP system topology of MAB and highlights the consideration of site-specific details.

Keywords: techno-economic analysis; heat pump system; CO_2 emissions; building thermal renovation;

Field of application for the findings: Building and system renovation; integration of renewable sources

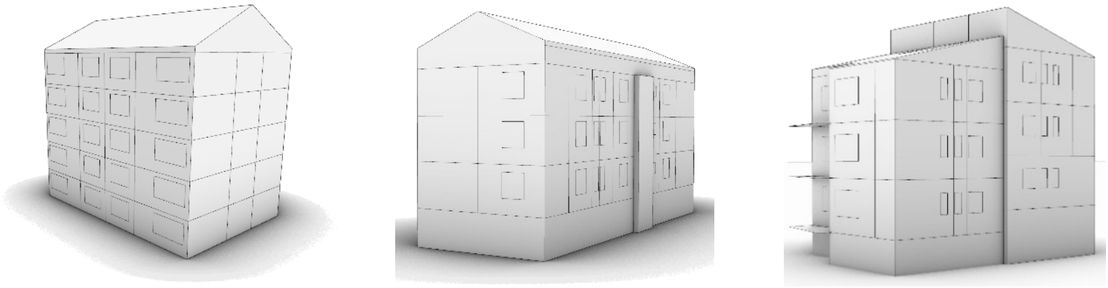
Addressed audience: Scientific audience, Planners

1. Introduction

Heat pumps (HPs) are gaining increasing relevance in Multi-Apartment Buildings (MABs) (Bloess et al., 2018) (Bernath et al., 2019), also in the context of renovations (Malevolti et al., 2024). Accelerating building renovation is essential to meeting the environmental and decarbonisation objectives ("Energy Performance of Buildings Directive," n.d.). Combining building thermal renovation and HP system installation is recommended, however, its implementation can be complex, as several elements contribute to the system and an overall optimization is required (Ochs et al., 2026). HP systems can serve for space heating demand (SHD), domestic hot water (DHW), or a combination of the two. Different distribution HP system configurations can be considered, e.g. 2-pipe system and 2+2-pipe system. The system choice affects the pipe thermal losses and the required temperature, thus HP performance. The overall optimisation depends on the goal, e.g. minimising costs or minimising energy demand (i.e. CO_2 emissions), which often leads to different designs. With on-site renewables (e.g. PV), the temporal variability of the PV energy production and building energy demand has to be considered, e.g. with variable CO_2 factors. An economic optimisation of a HP system via simulation is performed for example in (Vering et al., 2021). While dynamic simulations can capture control-dependent interactions, they are data-intensive and require an extensive modelling and simulation effort; a simplified pre-design approach is needed to compare different solutions. This study uses a spreadsheet approach to investigate different HP system solutions for MABs across multiple renovation levels, varying generation and distribution HP systems, and considering on-site PV self-consumption for three representative MABs. Results include CO_2 savings and an economic assessment covering investment, installation, maintenance, and operating costs over component lifetimes. Such a detailed techno-economic sensitivity analysis on building and system level has not been presented before.

2. Methods

Three existing MABs (A, B, and C) with decentralised gas boiler for SH and DHW constitute the study baseline. The buildings are shown in **Fig. *1*** and their key properties are summarised in **Tab. *1***.



A B C

Fig. 1: 3D-skecthes of the three buildings considered in the study

Tab. 1: Main properties of the investigated buildings

		A	B	C
Treated Floor Area (TFA)	[m^2]	1036	455	593
Number of floors	[-]	5	3	3
Number of apartments per floor	[-]	2	3	2
Number of people	[-]	30	10	16
SH demand	[kWh/(m^{2}a)]	164	247	234
SH Load	[W/m^2]	66	87	101
DHW demand	[kWh/(m^{2}a)]	21.6	13.7	14

The techno-economic analysis the three MABS includes a sensitivity analysis considering variations in the building energy quality, the HP systems topology (i.e. emission, distribution, generation) and its properties (e.g. insulation level of the distribution system) as well as the potential of on-site renewable (i.e. PV). The considered variants are listed in **Tab. *2***. The different distribution systems are: 4-pipe circulation (4p-C), 2+2 pipe with fresh water station (2+2p-FWS), 2-pipe with heat transfer station (2p-HTS), and 2-pipe with E-boiler (2p-EB). The piping insulation thickness ranges between 50% and 100 % of the pipe diameter.

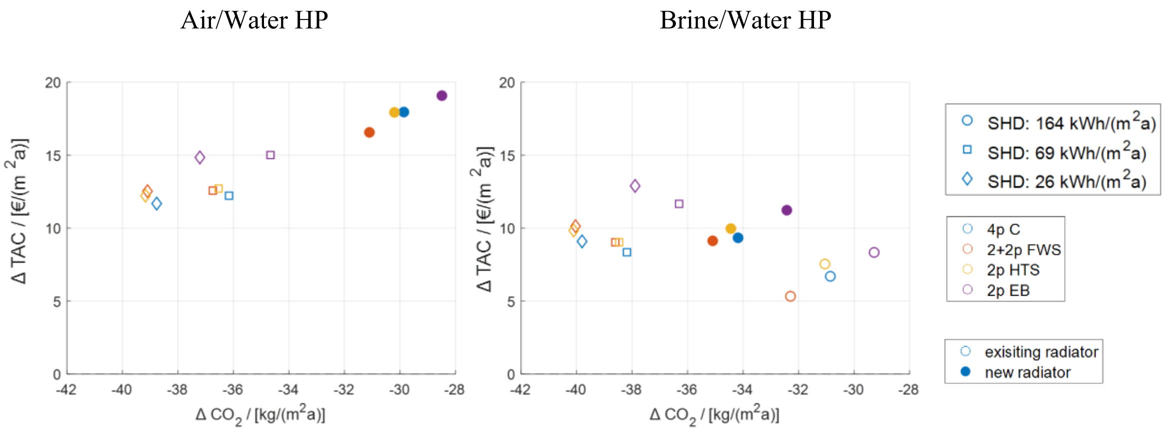
Tab. 2: Building and HVAC variants

Thermal envelope renovations	existent, first renovation, deep renovation
Emission system	Existing radiator, new radiator, fan convector
Distribution system	4p-C, 2+2-FWS, 2p-HTS, 2p-EB
Pipe insulation levels	Ins=50%, Ins=100%, Ins=150%
Type of HP (generation)	Air/Water, Brine/Water
PV	None, PV on the roof

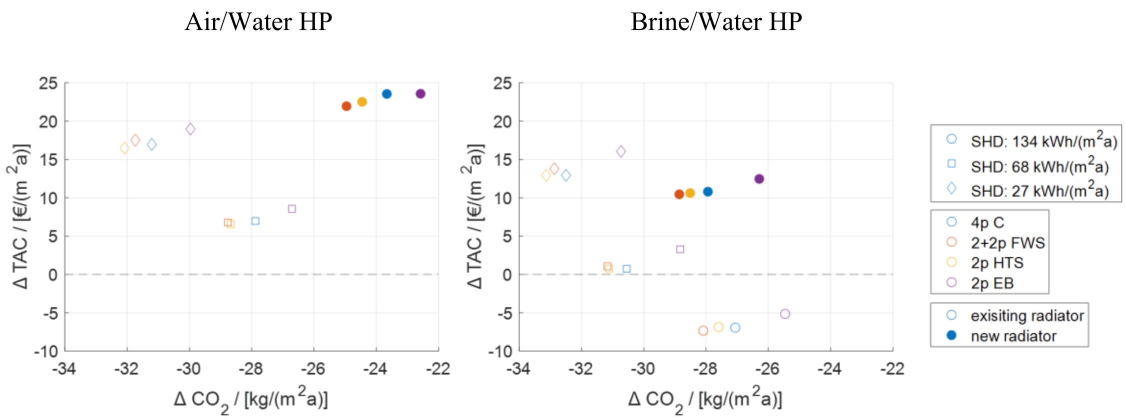
All the building and HVAC variants (see **Tab. *1*** and **Tab. *2***) are evaluated using a spreadsheet approach based on EN ISO 13790. Monthly energy demands are computed with the Passive House Planning Package (PHPP), extended with additional sheets for the techno-economic analysis including the hydronic system and the PV self-consumption. For all combinations, automatic sizing and dimensioning of the components is performed following European Standards. The economic analysis includes investment, installation, maintenance, and operating costs. In all cases, the generation system is assumed to be replaced, either with gas boilers (as built, which is the reference case for the economic analysis) or with the implementation of a HP system.

3. Results and Conclusions

Techno-economic results for some selected cases are shown in **Fig. *2***a for building A and in **Fig. *2***b for building C. Results are shown for different building thermal renovation (expressed with their SHDs), without PV and average pipe insulation level (Ins=100%). Savings in total annual cost (TAC) can be seen only in the case of building C and with brine/water HP. CO_2 emission reductions with respect to the reference case (existing building with replacement by gas boilers) range from around 22 kg/(m^{2}a) up to slightly more than 40 kg/(m^{2}a) with only slightly higher TAC. The renovation level has a significant higher influence than the HP system, however, within one renovation level, there are significant differences between the different HP system variants. A brine/water HP leads to lower TAC, despite higher investment costs. For brine/water HP, the non-renovated building yields the lowest costs (but also the smallest CO_2 savings). It is remarkable that different trends can observed between the two buildings. Building C shows economically advantageous cases, while for building A all the considered HP solutions are more expensive than the reference case.



(a)



(b)

Fig. 2: Techno-economic analysis of selected variants for the two cases: (a) Building A, (b) Building C.

The integral planning methodology is illustrated using three case studies of MABs. Multiple renovation depths and HP system concepts - including heat emission systems, HP system configuration, and source selection - are evaluated and compared with respect to their energetic, environmental and economic performance. The proposed workflow offers a scalable, knowledge-based planning approach to support the implementation of cost-optimal HP systems in renovations of MABs, thereby facilitating the transition towards a renewable and energy-efficient building stock.

4. References

Bernath, C., Deac, G., Sensfuß, F., 2019. Influence of heat pumps on renewable electricity integration: Germany in a European context. Energy Strategy Reviews 26.

Bloess, A., Schill, W.P., Zerrahn, A., 2018. Power-to-heat for renewable energy integration: A review of technologies, modeling approaches, and flexibility potentials. Appl. Energy.

Energy Performance of Buildings Directive [WWW Document], n.d. URL https://energy.ec.europa.eu/topics/energy-efficiency/energy-efficient-buildings/energy-performance-buildings-directive_en (accessed 4.25.25).

Ochs, F., Venturi, E., Magni, M., Breuss, S., Monteleone, W., Dermentzis, G., 2026. Simulation-based heat pump system design and optimization for multi-apartment buildings. 15th IEA Heat Pump Conference.

Malevolti, G., Rocchetti, A., Socci, L., 2024. Scenarios for the energy renovation of a residential building. In: E3S Web of Conferences. EDP Sciences.

Vering, C., Tanrikulu, A., Mehrfeld, P., Müller, D., 2021. Simulation-based design optimization of heat pump systems considering building variations. Energy Build. 251.