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SWEET P+D nanoverbund

nanoverbund

sweet swiss energy research for the energy transition

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Summary

Heating systems in buildings are designed to provide sufficient heating for the coldest expected days of the year. So, for most parts, they are underutilized. Retrofitting thermal connections between nearby buildings leads to a locally more efficient energy use as the most efficient heating system(s) can supply heat to all buildings. These connected buildings with adapted control (dubbed a "nanoverbund") can also provide more flexibility potential to upper-layer distribution grid operators or energy providers. Especially in the presence of heterogeneous building energy systems, energy storage and conversion technology can be utilized for the benefit of all parties/stakeholders. A pilot site installation of three buildings in the city of Basel shall be operated by a flexibility-aware control scheme to demonstrate the potential of the nanoverbund concept. Additionally, a stakeholder ecosystem study is conducted to understand the key interest in business and research opportunities of each involved party. This project is part of the SWEET PATHFNDR project portfolio, leveraging synergies in outcomes and findings.

Résumé

Les systèmes de chauffage des bâtiments sont conçus pour fournir un chauffage suffisant pendant les jours les plus froids de l'année. Dans la plupart des cas, ils sont donc sous-utilisés. L'installation de connexions thermiques entre des bâtiments proches permet une utilisation plus efficace de l'énergie au niveau local, car le(s) système(s) de chauffage le(s) plus efficace(s) peut(vent) fournir de la chaleur à tous les bâtiments. Ces bâtiments connectés avec un contrôle adapté (appelé "nanoverbund") peuvent également offrir un plus grand potentiel de flexibilité aux opérateurs de réseaux de distribution ou aux fournisseurs d'énergie à l'échelon supérieur. En particulier en présence de systèmes énergétiques hétérogènes, les technologies de stockage et de conversion de l'énergie peuvent être utilisées dans l'intérêt de toutes les parties prenantes. Un site pilote de trois bâtiments dans la ville de Bâle sera exploité par un système de contrôle tenant compte de la flexibilité afin de démontrer le potentiel du concept de nanoverbund. De plus, une étude de l'écosystème des parties prenantes est menée pour comprendre les principaux intérêts en matière d'opportunités commerciales et de recherche pour chaque partie impliquée. Ce projet fait partie du portefeuille de projets SWEET PATHFNDR, tirant parti des synergies dans les résultats et les conclusions.

Zusammenfassung

Heizsysteme in Gebäuden sind so ausgelegt, dass sie an den kältesten Tagen des Jahres genügend Wärme zur Verfügung stellen. Das bedeutet, dass die meiste Zeit die Heizungen nicht zu 100% ausgelastet sind. Werden Reihenhäuser mit einem thermischen Netz verbunden, kann lokal effizienter geheizt werden, da das Heizsystem immer am effizientesten betrieben werden kann, um den Bedarf aller Häuser zu decken. Diese thermisch verbundenen Gebäude mit angepasster Betriebsstrategie (genannt "nanoverbund") können auch mehr Flexibilität an die lokalen VNB und Energieversorger bereitstellen. Vor allem wenn verschiedene Gebäudeenergiesysteme vorhanden sind, können unterschiedliche Speicher-/Umwandlungstechnologien einen Mehrwert für alle Teilnehmer/Stakeholder liefern. Eine Pilotanlage mit drei Reihenhäusern mit flexibilitätsbewusstem Betrieb in Basel soll das Potential des nanoverbund Konzepts zeigen. Zusätzlich wird eine Studie zum Stakeholder-Ökosystem durchgeführt, um die zentralen Interessen an Geschäfts- und Forschungsgelegenheiten der beteiligten Parteien zu verstehen. Dieses Projekt ist Teil des SWEET PATHFNDR-Projektportfolios und nutzt Synergien in den Ergebnissen und Erkenntnissen.

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Abbreviations

DSO	Distribution Grid Operator
EBC	Energy in Buildings and Communities Programme
ICT	Information and communications technology
IWB	Industrielle Werke Basel
MPC	Model Predictive Control
VNB	Verteilnetzbetreiber

1 Introduction

1.1 Background information and current situation

The thermal energy demand of buildings and industries contributes significantly to global energy consumption. Most heating energy demands are still met by buildings' natural gas or oil heating systems. Increasingly, heat pumps contribute to the variety of possible building energy systems. Each heating system is sized to provide sufficient heating power on the coldest days of the year, plus an additional capacity reserve. Thus, heating systems are not utilized fully for most of the year.

Furthermore, neighboring buildings can have differing heating systems installed. Even if buildings are built simultaneously and identically in shape and size, over time, heating technologies need to be replaced by the owner, leading to a diverse set of heating systems installed in proximity. In most buildings, including row houses (multiple single/multi-family houses situated in one row or proximity), each house has its heating system.

Moreover, different carriers provide energy at different costs, which results in different ecological footprints and levels of availability. All energy carriers are consumed to fulfill the heat demand, regardless of their sustainability or potential scarcity. Some buildings might become uninhabitable in an (electric) blackout or natural gas shortage. One way to resolve this issue is to thermally connect nearby buildings to couple heating systems with different energy carriers. This provides a previously untapped flexibility potential to the connected buildings, referred to as a "nanoverbund" and the energy system.

In addition, from individual and societal perspectives, switching energy sources flexibly enhances energy system resilience and enables participation in and arbitrage across various energy markets. The operational strategy of the coupled heating systems plays a crucial role as it determines which energy carrier should be used to supply the connected buildings. Through coordinated utilization of heating systems, flexible operation can be offered to or coordinated with distribution grid operators for each connected grid. The flexibility potential of the connected nanoverbund is greater than the sum of individual buildings' flexibility potential because the exchange between energy carriers and consumers increases the possibilities for energy flow optimization.

In SWEET PATHFNDR[1] WP2, the flexibility potential in sector-coupled buildings combining mobility and building demand is investigated. On the building systems side, PATHFNDR WP3 focuses on developing technology descriptions and high-fidelity models. Similarly, in the SFOE SWEET PATHFNDR project, WP6 focuses on the business opportunities for stakeholders during the technology transition, relying on sector coupling in mobility. These results can be leveraged in this project.

1.2 Purpose of the project

In this project, the benefits of thermally connecting nearby buildings shall be investigated, quantified, and demonstrated. Additionally, the requirements for an overall economic case are analyzed. This project seeks to answer the following questions.

Q1: What technology mix and setting lead to an economical and ecological nanoverbund?

Q2: Who has to engage with whom and when?

Q3: How can we enable fairness between participants?

Q4: How does the gained flexibility aggregate on the DSO level? Can it reliably be utilized to benefit all parties involved?

[1] https://sweet-pathfndr.ch/

Q5: What interconnections and dependencies exist on the different connected energy carriers for flexibility utilization?

1.3 Objectives

The main goals of this project are as follows.

1. Identify a suitable neighborhood for the nanoverbund concept.
2. Implement flexibility-aware building operations and assess their integration potential with the upper grid level.
3. Determine the optimal mix and technologies settings for an economically and ecologically sustainable nanoverbund/heat prosumer community.
4. Determine the overall economic and ecological merit of the nanoverbund approach by comparing it to the initial individual heating system and other options, such as a centralized heating system.
5. Explore stakeholder motivations within this ecosystem and their corresponding value propositions.
6. Quantify the aggregated flexibility at the DSO level, evaluating its reliable use and benefits for stakeholders.

2 Executive summary of the activities and results to date

An overview of the project is illustrated in Figure 1. To visually aid in understanding and utilizing the expected results at the end of this project, Figure 2 presents a decision tree. Please note that not all results have been finalized and the rest of this report provides preliminary results. Moreover, the connections with PATHFNDR is illustrated in Figure 3.

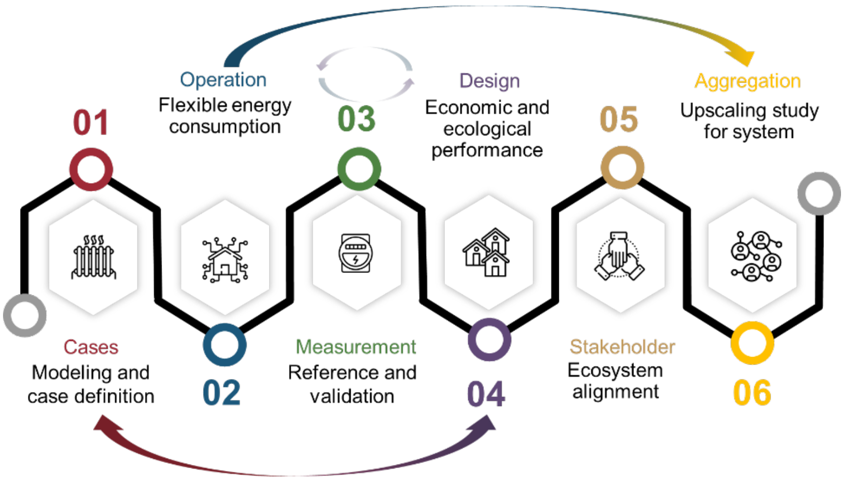

Figure 1. Overview of the nanoverbund P&D project and the initial interdependencies among WPs.

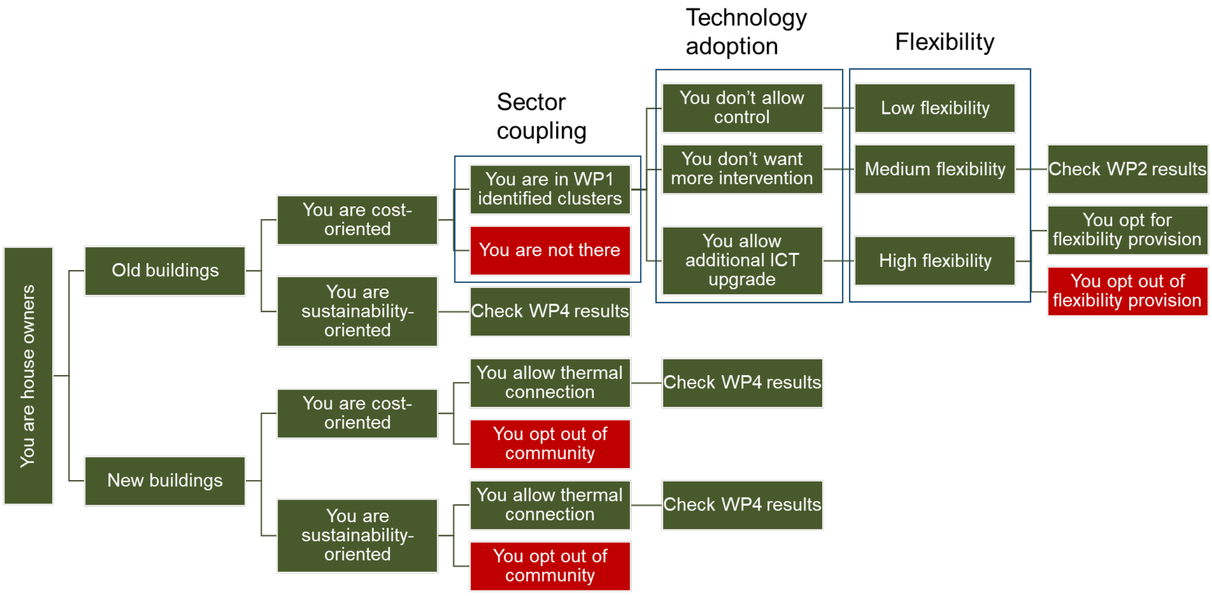

Figure 2. Example decision tree for interpreting and applying project results (note: some results are pending finalization).

Figure 3. Connections between the nanoverbund project (highlighted in yellow) and other WPs in PATHFNDR (highlighted in green).

The rest of this section summarize the preliminary results.

- **Definition of relevant cases**

Boundary conditions for the nanoverbund concept were developed, and the results were used to estimate the nanoverbund potential. The development of the heating demand from climate change and building stock evolution was considered, and respective scaling factors were given. This achievement from WP1 covers multiple spatial scales, ranging from household to cantonal levels as illustrated in Figure 4. Intermediate results showed that 107 building clusters in Basel resemble the pilot site and have the potential to replicate the solutions. The results were summarized in a report circulated within nanoverbund partners. The report will be updated according to feedback. The extended version of the report will be published in a journal paper containing detailed method description.

Figure 4. Graphical overview of boundary conditions for nanoverbund, spanning individual buildings, communities, to building clusters in a canton.

- **Analysis of centralized and distributed coordination schemes**

Both centralized and distributed coordination schemes facilitate building flexibility through control and automation, such as thermal inertia and buffer tanks. In simulation-based studies, the distributed scheme using alternating direction method of multipliers (ADMM) converges efficiently and quickly to the centralized approach, with any suboptimal gaps being negligible in practical applications. The simulation results show flexibility is utilized through predictive control at the individual building and the entire community levels, with mitigated privacy concerns in the distributed coordination scheme, as shown in Figure 5. The results are being extended to be included in a journal paper.

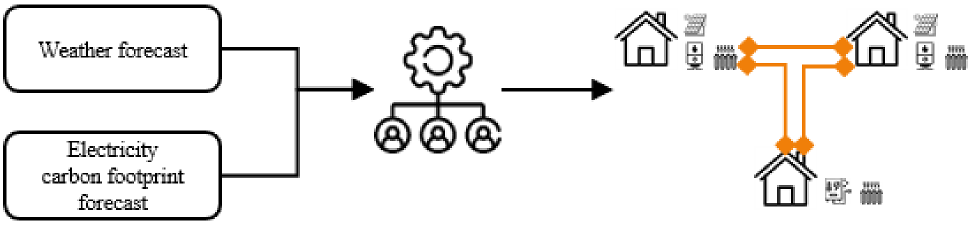

Figure 5. System configuration: one house is equipped with a heat pump, while the other two houses use their existing gas boilers.

- **Development of monitoring system and set up control interfaces**

The monitoring system and actuation interface were established, bridging multiple communication protocols and metering systems from different vendors and the underlying hardware that can be controlled. The key message is that there are sufficient off-the-shelf resources to roll out the necessary solutions for monitoring and actuation to replicate the results in a scalable way. The scalability is achieved by reusing existing technologies and installations as much as possible, while the scale of adoption in real life is being explored by IWB. Moreover, Figure 6 gives an example energy cost calculation using the measurements, which highlights the cost saving (i.e., 605 CHF in 2024) with the nanoverbund.

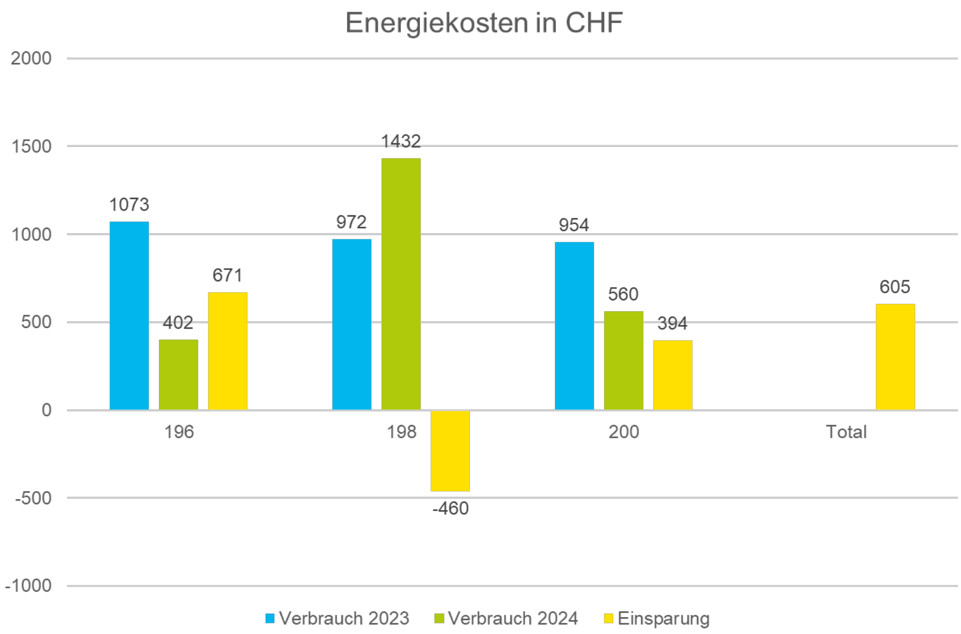

Figure 6. Energy cost calculation using measurements from 2024.

- **Creation of an economic and environmental assessment framework, including sensitivity analysis**

A modeling framework was developed to assess a heat economic and environmental viability, giving ranges of solutions with Pareto fronts. Additional sensitivity analysis was performed. An essential factor decides whether a heat prosumer community is economically and environmentally viable. It is preliminarily found that the loss threshold to choose a thermal network is 0.1/m (meaning 10% energy loss per 1 meter of pipe). If individual buildings in a nanoverbund decide to decarbonize without coordination, installing a thermal network becomes less attractive. With cheap and emission-free wood pallets, wood boilers are the preferred clean energy source for the neighborhood compared to ground-source heat pumps. The optimal solution returns to the base case solution only when the wood price increases significantly.

- **Stakeholder workshops and interviews**

Stakeholder workshops and interviews were conducted, obtaining first-hand insights from practitioners such as IWB and researchers such as Empa on how they have managed their innovation journey. For example, how was the onboarding of the customers; how were additional sustainable and flexibility technologies coupled (integration of solar thermal heating); how some actors were replaced by others etc. The collected inputs will provide information for the ecosystem alignment study. To this end, the actors that will contribute to specific activities to enable the materialization of the value proposition will be shown. This mapping will allow us to identify the factors and barriers to sector coupling technology adoption for customers and firms. So far, it is understood that policy was a main trigger for the innovation process of the "nanoverbund". Also, prior innovations were disjunct from that "nanoverbund" solution. For example, IWB had ongoing pilots, such as using waste heat of servers to heat houses, which most likely contributed to firm-internal learning effects. This will most likely have contributed to the firm's internal innovation processes.

More specifically, 24 semi-structured interviews were conducted to understand the "nanoverbund" ecosystem. Three different stakeholder groups participated: (1) Customers (3 interviews), (2) firm representatives (11 interviews + 1 from authority), and (3) researchers (9 interviews) to get a diverse picture. Three project meetings will be used as an additional data basis. With the input from PATHFNDR WP6, the innovation ecosystem was mapped. The sketch of the "nanoverbund" ecosystem was validated by two firm representatives and two researchers.

- **Quantification of flexibility using optimal control-based approach**

The flexibility of a simplified nanoverbund system with the operation of a Model Predictive Controller (MPC) was theoretically quantified. The flexibility obtained with an MPC provides an upper boundary for the flexibility produced by the real system. The results show a strong time dependence in the available flexibility due to exogenous parameters, such as the ambient temperature, and internal states, such as the thermal energy storage's charge state. The results have been published in a conference paper (Tajoli et al. 2024). The results here form the basis for aggregation and upscaling study in WP6.

More specifically, a system of two buildings, one with a heat pump and one with a gas boiler, was simulated in Python using the simulation platform ReSIM, using a first-order thermal model of the buildings and the thermal energy storage, as illustrated in Figure 6. The flexibility envelope concept from (Gasser et al. 2021) and synthesis report on definitions and metrics (Bardow et al., 2023) was used to capture time-varying energy and power flexibility. An optimal controller with a rolling horizon was used to determine the heat generation and exchange between the buildings at each timestep, considering the thermal comfort and energy savings. The second step calculated the system's resilience to constrained power consumption: the time duration the system can sustain itself within the temperature boundaries is identified. The result is exemplified in Figure 7.

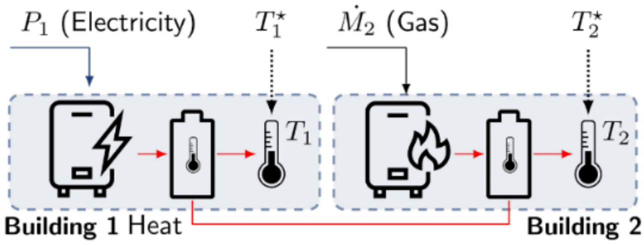

Figure 7. System configuration of a two-building system with heat pump and gas boiler. The thermal connection is in red.

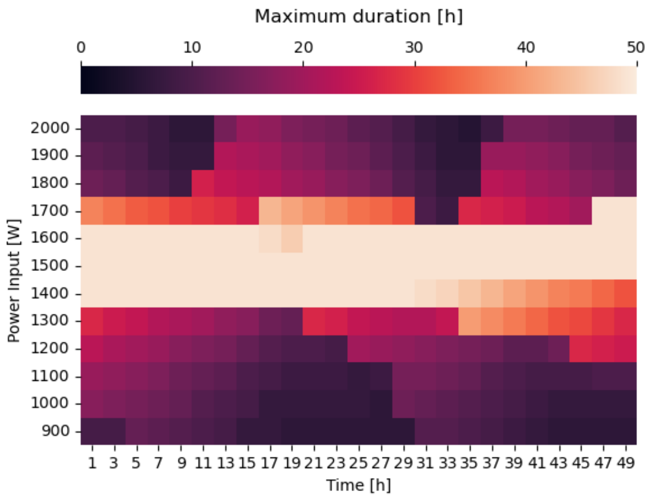

Figure 8. Flexibility mapped over two days: each square indicates the system's sustainable duration within operating limits at power levels indicated on the y-axis.

- **Assessing international pilot projects demonstrating flexibility at the community level**

Aside from the activities planned in this project, a literature review jointly with the International Energy Agency EBC Annex 82 working group[2] was carried out in parallel to survey key toolchains for utilizing flexibility in buildings and the pilot demonstration projects utilizing flexibility at this level. The main insight relevant to nanoverbund was that there is still a scarcity of pilot projects utilizing flexibility at a large scale (examples can be found in Table 3 of Le Dréau et al. 2023), even though there is a considerable volume of research dedicated to developing control algorithms, simulations, and analysis. Flexibility utilization is relatively limited. This review highlights that more pilot studies are also needed to test and facilitate novel demand-side flexibility solutions. Additionally, closer cooperation between the grid side and the demand side is necessary to overcome the complexity of designing for flexibility and offering successful market solutions. Lastly, cross-sectoral synergies (e.g., buildings and transportation/mobility, buildings and power) should be considered in future research to expand flexibility market perspectives. The results were published in a journal paper (Le Dréau et al. 2023).

[2] https://annex82.iea-ebc.org/meetings

3 Outputs and outreach to date

Publications (peer-reviewed or others)

Description: author(s), title, journal or type of publication, year of publication, doi

Public oral and visual presentations (scientific or broad audience)

Description: author(s), title, name of the event and location, year of presentation
Born, Dominik; 2024-03-06; Dialogveranstaltung Mausacker; Weihermatthalle Reinach, Gemeinde Reinach BL
Born, Dominik; 2024-03-21; Infoveranstaltung Gemeinde Bettingen; Gemeindesaal; Gemeinde Bettingen
Born, Dominik; Nanoverbund - Wärme smart und flexibel teilen, Info- und Diskussionsveranstaltung "Heizdialog Mausacker", Rainach BL, 06.03.2024, ***https://www.reinach-bl.ch/de/aktuell/news/meldungen-projekte/stadtentwicklung/Mausacker.php***
SRF Audio, radio broadcast, IWB-Lösung: Verbünde statt Fernwärme, 11.03.2024, ***https://www.srf.ch/audio/regionaljournal-basel-baselland/iwb-loesung-verbuende-statt-fernwaerme?id=12553085***
Semester Thesis, Bernadino, B. (supervised by Hanmin Cai, Philipp Schuetz and Binod Koirala) (2024) Economic and Environmental Assessment of Heat Prosumer Communities

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Gasser, J., Cai, H., Karagiannopoulos, S., Heer, P., & Hug, G. (2021). Predictive energy management of residential buildings while self-reporting flexibility envelope. *Applied Energy*, *288*, 116653.

Le Dréau, Jérôme, et al. "Developing energy flexibility in clusters of buildings: A critical analysis of barriers from planning to operation." *Energy and Buildings* (2023): 113608.

Tajoli, C., Heer, P., & Hug, G. (2024). Quantification of the flexibility enhancement with micro-scale multi-energy coupling. *Proceedings of the IEEE Innovative Smart Grid Technologies Conference (ISGT 2024), in press.*