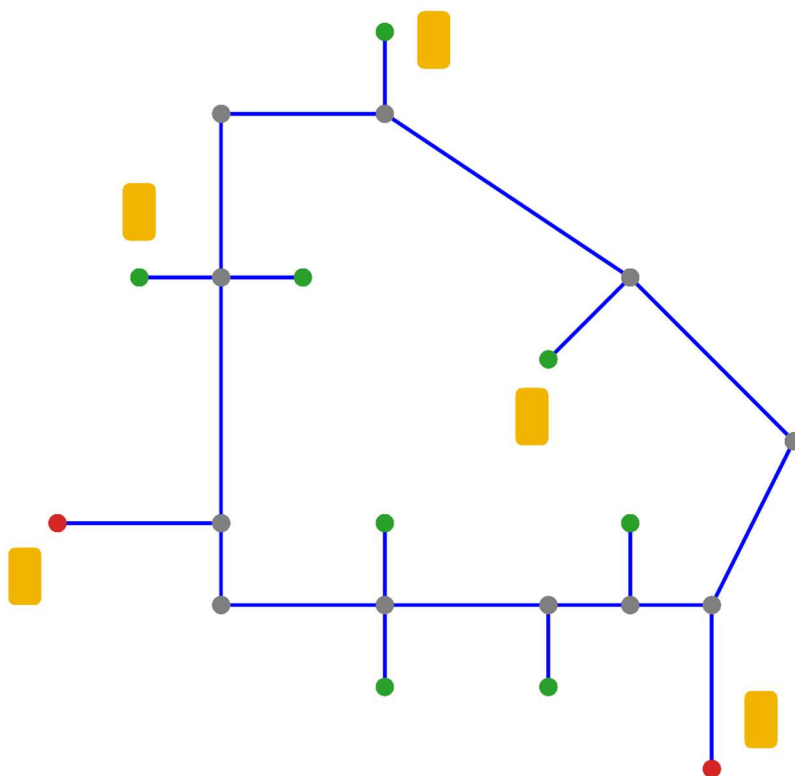




Final report of 24 July 2026

DecenTGrids

Decentral Storages for Energy Management in Thermal Grids – Optimal Sizing and Operation



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The authors bear the entire responsibility for the content of this report and for the conclusions drawn therefrom.



Summary

Thermal storages support the design and operation of district heating networks by reducing peak loads, relieving local grid bottlenecks, and improving the integration of renewable or surplus heat. Decentral thermal storages, installed close to consumers or in network branches, are especially relevant where space for central storage is limited or where additional consumers are to be connected without immediately replacing pipes. This project analysed decentral thermal storages using a biomass district heating network and two Swiss case studies. The dynamic optimization tool optihood was extended for spatial thermal grid modelling, and a practical planner toolchain was developed with PeakAnalyser and THENA. The results show that decentral storages can significantly reduce peak heating power, especially where short load peaks or local pipe constraints occur. In the investigated cases, peak reductions of up to 36 % were achieved. However, decentral storage is economically attractive mainly when the reduced peak power avoids infrastructure expansion or costly peak operation.

Zusammenfassung

Wärmespeicher unterstützen die Auslegung und den Betrieb von Fernwärmenetzen, indem sie Lastspitzen reduzieren, lokale Netzengpässe reduzieren und die Einbindung erneuerbarer Wärme oder Abwärme verbessern. Der Einsatz dezentraler thermischer Speicher, die nahe bei den Verbrauchern oder bei Netzverzweigungen installiert werden, ist besonders dann interessant, wenn für eine zentrale Wärmespeicherung nur begrenzt Platz verfügbar ist oder zusätzliche Verbraucher angeschlossen werden sollen, ohne dass Leitungen ersetzt werden müssen. Im Projekt wurden dezentrale thermische Speicher anhand eines Biomasse-Fernwärmenetzes sowie zweier Fallstudien analysiert. Die dynamische Optimierungs-Software optihood wurde für die räumliche Modellierung thermischer Netze erweitert, und mit PeakAnalyser und THENA wurden praxistaugliche Werkzeuge für Planer entwickelt. Die Ergebnisse zeigen, dass dezentrale Speicher die Spitzenleistung deutlich reduzieren können, insbesondere wenn kurze Lastspitzen oder lokale Leitungsengpässe auftreten. In den untersuchten Fällen wurden Reduktionen der Spitzenleistung von bis zu 36 % erreicht. Wirtschaftlich attraktiv sind dezentrale Speicher jedoch vor allem dann, wenn die reduzierte Spitzenleistung Netzausbauten oder teuren Spitzenlastbetrieb vermeidet.

Résumé

Les stockages thermiques contribuent au dimensionnement et à l'exploitation des réseaux de chauffage à distance en réduisant les pointes de charge, en soulageant les congestions locales du réseau et en améliorant l'intégration de chaleurs de sources renouvelables ou excédentaires. Les stockages thermiques décentralisés, situés à proximité des consommateurs ou dans les branches du réseau, sont particulièrement pertinents lorsque l'espace disponible pour un stockage central est limité ou lorsque de nouveaux consommateurs sont raccordés sans remplacer immédiatement les conduites. Ce projet a analysé les stockages thermiques décentralisés à l'aide d'un réseau de chauffage à distance alimenté par biomasse ainsi que de deux études de cas suisses, Wallisellen et Meilen. L'outil d'optimisation dynamique optihood a été étendu pour la modélisation spatiale des réseaux thermiques, et une chaîne d'outils pratique destinée aux planificateurs a été développée avec PeakAnalyser et THENA. Les résultats démontrent que les stockages décentralisés peuvent réduire considérablement la puissance de pointe, en particulier lors des pointes de charge courtes ou lorsque des contraintes locales dans les conduites apparaissent. Dans les cas étudiés, des réductions de pointe aussi grand que 31-36 % ont été obtenues. Toutefois, les stockages décentralisés sont économiquement avantageux principalement lorsque la réduction de la puissance de pointe permet d'éviter des extensions d'infrastructure ou une exploitation en pointe coûteuse.



Main findings

- Decentralized thermal storage can reduce short heat-demand peaks and relieve local bottlenecks in district heating networks. This can support the cost-effective expansion and decarbonization of Swiss thermal grids, especially where space for central storage is limited or where pipe capacity is constrained.
- Across the investigated networks, optimized decentralized storage reduced peak heating power in the range of 13-36 %, depending on the network, storage size and optimization objective. The highest reductions were 31 % in the idealized biomass network, 27-36 % in Wallisellen and 15-28 % in the case study 2.
- The economic benefit is case-specific and depends on the value of the avoided peak capacity. Decentralized storage is most attractive when it helps avoid pipe replacement, larger heat generators or costly peak load operation.
- Decentralized storage is not a universal substitute for larger pipes or heat generators. Its value must be assessed using real demand profiles, network constraints and control strategies; the PeakAnalyser + THENA workflow developed in this project gives planners a practical way to perform this early-stage assessment.



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List of abbreviations

ASHP	Air-source heat pump
BHE	Borehole heat exchanger
CAPEX	Capital expenditure
COP	Coefficient of performance
CSV	Comma-separated values
DH	District heating
DHN	District heating network
DHW	Domestic hot water
DN	Diamètre Nominal (French) or Nominal Diameter: standardized, unitless metric code used to designate the size of pipes, valves etc.
EZ	Energiezentrale (German) or Energy centre
GSHP	Ground-source heat pump
GUI	Graphical user interface
HP	Heat pump
KMR	Kunststoffmantelrohr (German) or plastic jacket pipe, refers to the standardized pre-insulated bonded pipe system (steel service pipe, polyurethane insulation, polyethylene outer casing)
KVA	Waste incineration plant
LCOH	Levelized cost of heat
MFH	Multi-family house
MILP	mixed-integer linear program
OPEX	Operating expenditure
PV	Photovoltaics
SFH	Single-Family House
SFOE	Swiss Federal Office of Energy
SH	Space heating
STC	Solar thermal collector
TES	Thermal energy storage



1 Introduction

1.1 Context and motivation

Thermal networks are a central pillar of the Swiss federal government's energy strategy. In all net-zero scenarios of the Energy Perspectives 2050+, the heat provided by district heating is to be significantly increased from around 11 TWh today to up to 18 TWh (Kirchner et al., 2020). In order for this expansion to take place as quickly and cost-effectively as possible, the thermal grids must be optimally dimensioned and operated. It is also important to substitute the still relevant fossil fuel share, which is currently around 19.2 % in Swiss thermal networks (Thermische Netze Schweiz TNS, 2026).

Heat generators in district heating networks generally operate more efficiently when they are in continuous operation, thereby reducing start-up losses, and when they are operated with minimal fluctuations in heat output. To support consistent continuous operation, central thermal storage tanks are often installed in the central heating plant. However, there may be limited or no space available. The decentralized integration of storage tanks, e.g. directly at consumers' premises opens up many possibilities to find locations with available space.

This report analyses the integration of decentral thermal storage systems into heating networks. It investigates the extent to which these decentral storage tanks can reduce load peaks over different time scales and thereby enable smaller pipe diameters, or alternatively allow the network to be extended by connecting more consumers. Thermal storage is also a prerequisite to achieve significant shares of fluctuating renewable energy sources, such as solar thermal energy or PV & heat pumps or surplus heat of waste incineration plants.

There is currently a lack of recommendations and simple tools for designing decentralized storage systems in particular and for quantifying the advantages when planning or expanding thermal grids. Similarly, little is known about good charging strategies for such storage systems. This project aims to create a better basis for this and provide tools to integrate the effects of decentral storage capacities into the sizing process of piping systems.

1.2 Project objectives

This project aims to answer the following overarching questions and deliver the following practical outcome:

- To what extent and through what savings can the costs and CO₂ emissions of heat supply via thermal networks be reduced through the use of decentralized thermal storage? (see *Chapters 4 and 6*)
- What are the optimal dimensions for decentralized storage in typical heating networks, including warm networks with biomass or waste heat from waste incineration plants as well as networks with heat pumps? (see *Chapters 4 and 6*)
- Which simple operating strategies for decentralized storage systems can be used to smooth load peaks in heating networks (especially the daily morning peaks)? (see *Chapter 7*)
- The project should also result in a simple user tool that enables planners to estimate the impact of thermal storage systems on peak loads in the grid and grid costs. The planner should be able to vary the storage type, positions in the grid and storage sizes. (see *Chapter 5*)



1.3 Thermal district heating networks in Switzerland

While the majority of the Swiss district heating networks (DHN) are powered by wood (biomass), the greatest quantity of energy is distributed by grids connected to waste heat (waste incineration plants or industrial waste heat) (Thermische Netze Schweiz TNS, 2026). DHNs powered by heat pumps and environmental heat currently account for a smaller share, but they represent the DHN type with the highest growth rate and expectably the greatest future potential. Table 1 shows characteristics of typical thermal networks found in Switzerland. Beyond the energy source, each DHN was characterized by its power, length, temperature levels, and topology.

Table 1: Representative DHNs in Switzerland with their parameters (Source: project BigStoreDH¹).

	Biomass	Environmental heat	Waste heat
Power [MW]	0.9	3.7	23.3
Demand [GWh/a]	1.5	7.2	47.6
Network length [km]	1.3	2.6	19.8
Temperatures (flow / return) [°C]	80 / 50	70 / 40	90 / 50
Grid topology	One branch	Multiple branches	Mesh
Number of connections	21	32	573

1.4 Thermal storages in thermal networks

Central seasonal storage systems have already been covered in various studies, see e.g. Haller & Ruesch (2019), Schädle et al. (2018). The SFOE project BigStoreDH¹ deals in depth with the economic and regulatory boundary conditions as well as the energy potential of large central heat storage facilities in Swiss district heating networks.

Decentralized thermal (swarm) storages in heating networks have been comparatively little discussed and, to our knowledge, hardly implemented. A case study in which the advantages of two decentralized storage systems for two sub-grids are discussed is provided by Schuchardt (2017). Another interesting case study for a district grid with 129 buildings shows that if each building is equipped with a decentralized storage capacity of 1.4 hours times its own peak demand, the power peaks in the grid can be completely smoothed out (Röder et al., 2021). Both studies are rather illustrative and for a single situation but show the capabilities of decentralized storage.

Possible advantages of integrating storage in thermal networks

Larger thermal storages with capacities above approx. one hour of the heating demand – installed both centrally and decentral – promise the following benefits for thermal grids:

- Reduction of thermal peak loads so that, for example, fossil peak load boilers are used less or are no longer necessary. Thus, decarbonization of thermal grids.

¹ See <http://www.spf.ch/bigstoredh>



- Better utilization of excess heat from constant waste heat sources (e.g. waste incineration plants) or of fluctuating heat sources such as solar thermal systems.
- In the case of heat pump (HP) systems (centralized and decentralized): Reduction of electricity peak loads of the HP and thus cost reduction potential for the grid operator or the consumer. The storage also provides flexibility to operate the heat pumps during periods with a higher COP or a lower CO₂ footprint of the electricity mix, provided that the storage capacity is sufficient to shift heat production between these periods.
- In the case of combined heat and power plants: Flexibility to operate the system in an electricity-led and therefore cost-optimized manner.

Decentralized storage systems can also offer the following possibilities

- Reduction of heating power peaks in the distribution grid (line cross-sections, transfer stations)
- Reduction of pump power consumption in the distribution grid
- Flexibility for the expansion of the thermal grid in the event of capacity bottlenecks in the distribution system and in the periphery.
- Flexibility for the integration of decentralized heat generators



2 Approach

The project analyses the effects of decentralized thermal storage on the design and operation of district heating networks (DHNs). One generic network that is based on a real biomass DHN and two case studies with DHN from utilities are used for the investigations. The analysis is carried out using software tools (optihood, PeakAnalyser and THENA) that have been adapted or developed specifically to model decentralized storage.

Analysis of the benefit of decentral storage in district heating network (DHN):

For the analysis of decentral storages, a generic district heating network is developed, which is based on a real biomass DHN (Chapter 3) whose heat demand and pipe diameters are adapted for the purpose of our analysis (Section 4.2).

The effects of decentral thermal storages on this exemplary DHN are investigated using the software optihood (Section 4.3).

For further knowledge gain, two DHN with heat supply from heat pumps, one of the DHN planned and one in operation since 2021, are analysed as case studies (Chapter 6). The heat pumps in the case studies are either coupled with boreholes or use waste heat as their source.

Within the scope of this project, decentral thermal storage is assumed to be charged from the DHN and discharged only to supply the heat demand of the respective building. Feeding stored heat back into the DHN is not considered. Also, the model determines individually for each building whether a storage system is installed. The storage therefore provides local load shifting but does not act as a decentralized heat source for the wider network.

Software-Tools for the analysis of district heating networks:

The investigation of the technical and economic impact of decentralized thermal energy storages on DHN is performed with the **dynamic optimization tool optihood**. Within the project, the optihood tool is adapted so that the spatial extent of DHN and decentralized thermal storage can be modelled (Section 4.1).

Because the dynamic optimization in optihood can be computationally intensive, we designed a separate, user-friendly **practical toolchain with the two software tools PeakAnalyser and THENA** specifically for network planners. This approach is more iterative and manual compared to optihood, combining visual data analysis (PeakAnalyser) with an accessible Excel-based sizing tool THENA (Chapter 5).



3 Generic district heating network and general framework

3.1 Generic district heating network

For analysing the effects of decentral storages in district heating networks (DHN), the real biomass DHN of the municipality Landiswil, canton Bern, is used as basis. As the piping of the network in Landiswil is sized for possible future expansions and therefore oversized in the current operation, all network sections are individually reduced to smaller norm (DN) sizes and the heat demand of the buildings is scaled up. As a result of these measures, potential bottlenecks in the heat supply, if e.g. consumers are added to the network in future, are artificially created and the effect of decentral storages on reducing these bottlenecks can be analysed.

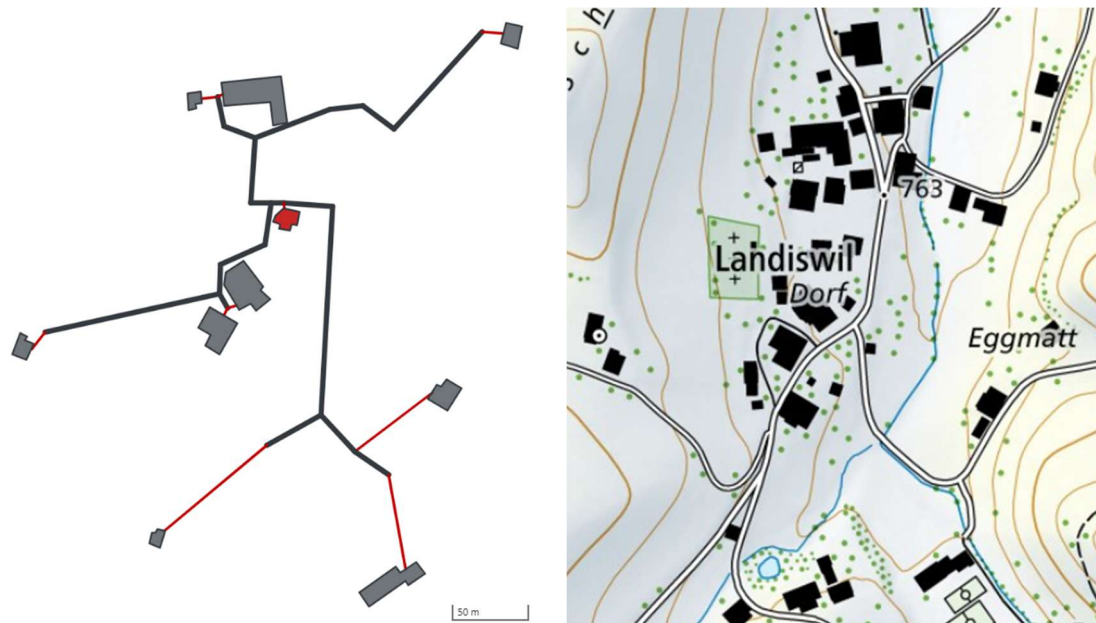


Figure 1: Biomass district heating network in Landiswil with ten buildings. Left: the central energy producer is highlighted in red, supplying the consumer buildings shown in grey. Thick grey lines represent the primary transport pipes, while the thinner red lines connect individual buildings to the main network (map: swisstopo).

The required data and detailed information on the biomass DHN in Landiswil, investigated in this study, was provided to the consortium by a partner on the advisory board. It connects ten buildings: a school, a production warehouse, and eight residential buildings with different sizes. The DHN is powered by wood, extends over 1.1 km, and has a heat demand of approximately 0.43 GWh at a supply temperature of 85 °C. The buildings are assumed to be old and poorly insulated. Most have both space heating and domestic hot water demand, and either already have supplementary storage installed or could accommodate it in the future. Figure 1 illustrates the network structure.

3.2 Demand profiles

Typical space-heating and domestic-hot-water profiles were generated for each building using the nPro tool (Wirtz, 2023). Because nPro produces a standard profile per building type, the buildings of a given



type would all have the peak demand at the same time. To obtain a more realistic aggregate load, the individual profiles are shifted in time so that the peaks of the same type of buildings do not all coincide, which smooths the DHN's combined demand. The time shifts are drawn from a normal distribution with a mean of 0 h and a standard deviation of 1 h and are limited to the range of -2 h to $+2$ h. This approach is used both for the biomass DHN and for one of the case studies including heat pumps. For the case study 2, measurement data is used where available and nPro fills the gaps. The demand profile assumptions made within the case studies are described in detail in Section 3.1. Table 2 summarizes the specific space heating and hot water demands of the different building categories considered from the nPro tool. Domestic hot water is based on a consumption of $21 \text{ kWh/m}^2/\text{a}$ for all the three considered types of buildings. It should be noted that this identical value refers only to the annual specific DHW demand per unit floor area. The temporal DHW demand profile differs between building categories, meaning that the DHW loads are not identical over time despite having the same annual value. The space heating demand of residential buildings depends on the age and the type of building (MFH, SFH) and on the climatic region. An average reference year for the closest available weather station Langnau im Emmental (LAG) is used within the simulations. The space heating demand of the residential buildings within the nPro tool ranges from 15 to $244 \text{ kWh/m}^2/\text{a}$ (for all available building categories); in Landiswil DHN, it ranges from 92 to $122 \text{ kWh/m}^2/\text{a}$ as only buildings with intermediate demand are present.

Table 2: Space heating and hot water demand values used in the nPro calculations.

	Space heating demand [$\text{kWh/m}^2/\text{a}$]	Domestic hot water demand [$\text{kWh/m}^2/\text{a}$]
Residential	15 - 244	21
School	112	21
Production Warehouse	92	21

Figure 2 illustrates the annual hourly domestic hot water demand profiles for the largest residential building, the production warehouse, the school, and the total demand of Landiswil DHN. Compared with the space-heating demand, the domestic hot water demand has a much weaker seasonal variation and remains present throughout the year. Nevertheless, lower values are observed during the summer months. The school profile shows a clear occupancy-related pattern, with substantially reduced demand during weekends and holiday periods. The production warehouse and residential profiles are more continuous, and together with the school profile they form the aggregated network demand.

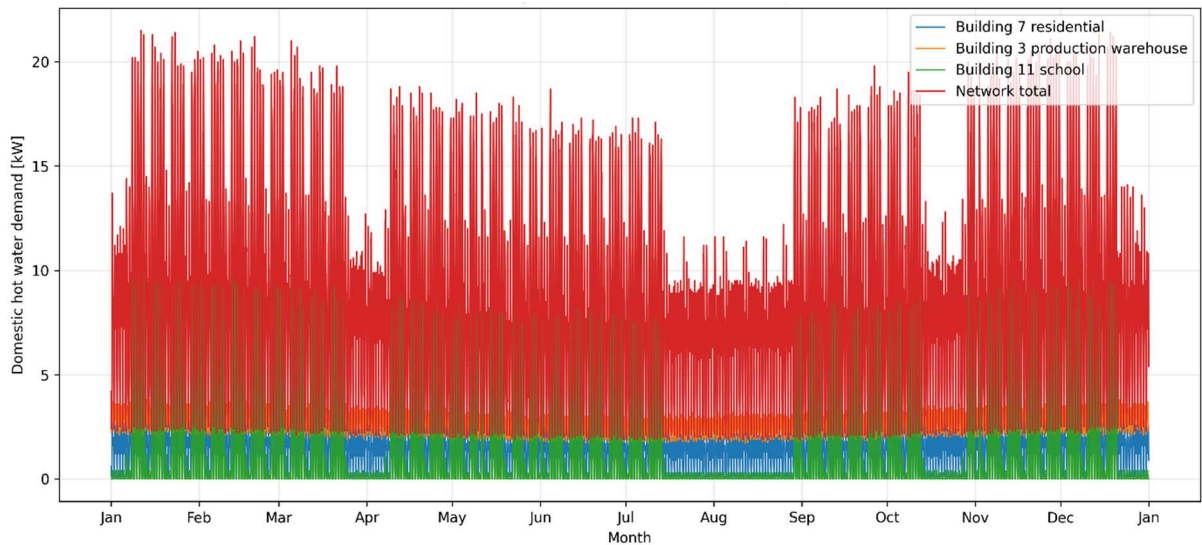


Figure 2: Example of annual hourly domestic-hot-water demand of a school building, one residential building and the network total in Landiswil.

Figure 3 shows the domestic hot water demand over a Sunday and the following Monday in January. The residential building shows the typical morning and evening demand peaks, while the production warehouse has a comparatively steady profile. The school demand is almost absent on Sunday and increases clearly during school hours on Monday. This leads to a higher total network hot water demand on the weekday than on the weekend.

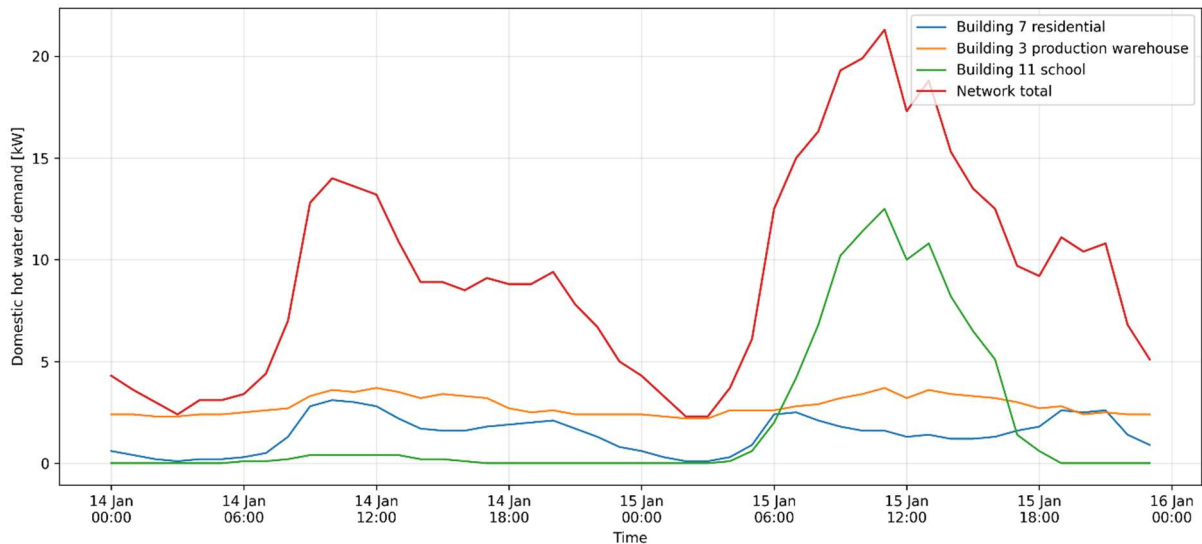


Figure 3: Hourly domestic hot water demand of a school building, one residential building and the network total on Sunday (14 January) and Monday (15 January).

Figure 4 illustrates the annual hourly space heating demand profiles of the same buildings and of the network total. The demand follows the expected seasonal pattern, with high values in winter and very low or nearly zero values in summer. The school has the highest single building space heating peak, while the production warehouse also contributes a significant part of the annual heat demand. The residential example building has a smaller but still visible contribution to the total network load.

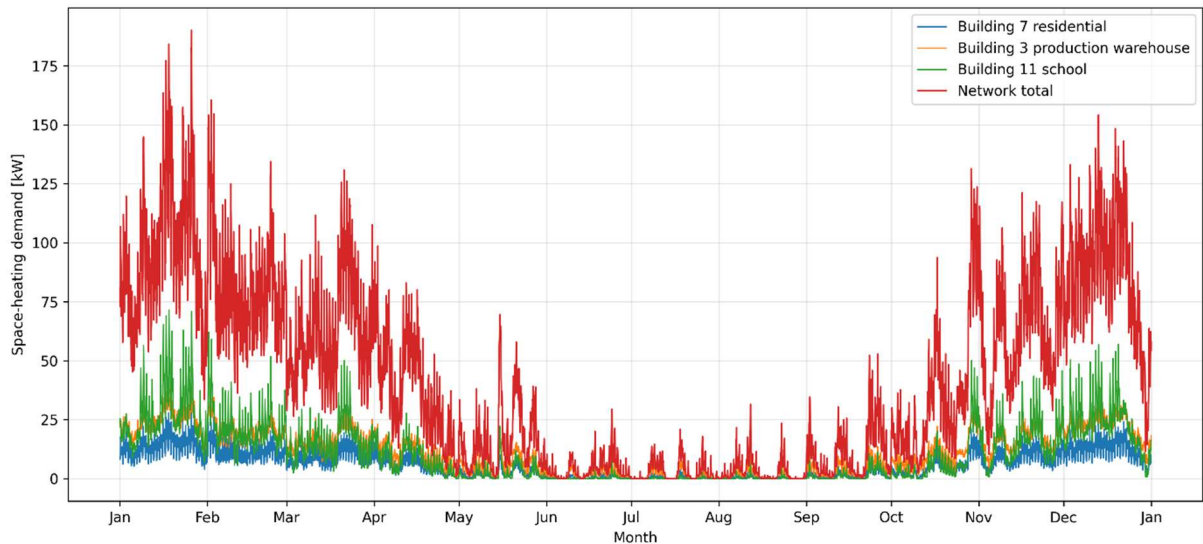


Figure 4: Annual space heating demand of a school building, one residential building, an office and the network total for an average reference year in Landiswil.

Figure 5 shows the space heating demand over the selected Sunday and Monday in January. The profiles show higher demand during the morning hours, especially for the school and the production warehouse. The network demand is higher on Monday than on Sunday because the school demand is active on the weekday and because the individual building profiles coincide more strongly during working hours.

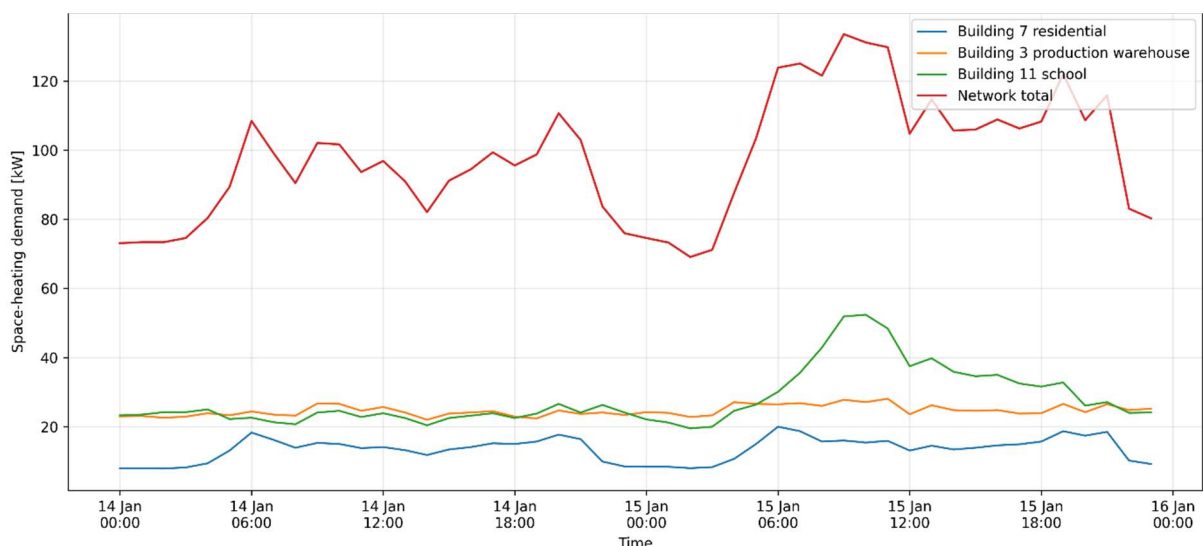


Figure 5: Hourly space heating demand of a school building, one residential building, an office and the network total on Sunday (14 January) and Monday (15 January) of an average reference year.

The total heating demand of the Landiswil DHN amounts to 0.43 GWh/a, which is only approx. 30 % of the demand of typical biomass networks in Switzerland according to Table 1. Space heating accounts for 355 MWh/a, corresponding to about 83 % of the total demand, while domestic hot water accounts for 75 MWh/a, or about 17 %. The peak heating demand reaches about 208 kW and occurs on



26 January at 08:00. The highest annual building demand is found for the production warehouse, followed by the school and the largest residential building. The largest individual peak demand occurs in the school building, which reaches 81 kW.

Figure 6 summarizes the annual heat demand and the peak demand of each building, considering both space heating and domestic hot water consumption. Bar B3 corresponds to the production warehouse, B11 the school, and B7 the largest residential building, which was used as the example in the preceding figures.

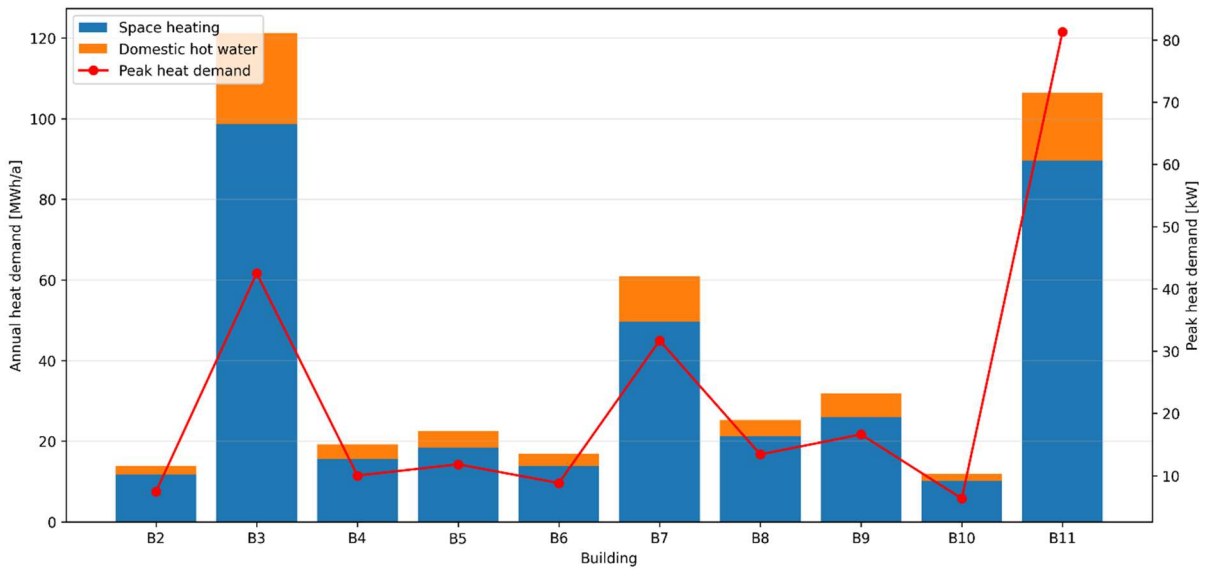


Figure 6: Annual heating demand and peak demand of each building in the Landiswil biomass DHN (B3: pro-duction warehouse, B2 to B9: residential buildings, B11: school).

3.3 Assumptions for costs and greenhouse gas emissions

The assumptions regarding the costs and greenhouse gas emissions are presented in Table 3. The costs associated with storage systems have been disaggregated into two distinct categories: base investment costs, which are independent of storage capacity, and costs per unit of storage capacity.² For storage volumes up to 2 m³, the investment cost (including integration/piping) is calculated as:

$$C_{\text{stor}}[\text{CHF}] = 2840 [\text{CHF}] + 605 [\text{CHF}/\text{m}^3] * V[\text{m}^3]$$

where C_{stor} is the storage investment cost in CHF and V is the storage volume in m³.

For storage volumes above 2 m³ and up to 20 m³, the following simplified cost function is used:

$$C_{\text{stor}}[\text{CHF}] = 7550 [\text{CHF}] + 827 [\text{CHF}/\text{m}^3] * V[\text{m}^3]$$

This second function includes the additional costs for on-site welding of the storage casing segments. The cost function used for the storage tanks is shown in Figure 7.

² Storage cost assumptions are based on communication with a Swiss storage tank provider

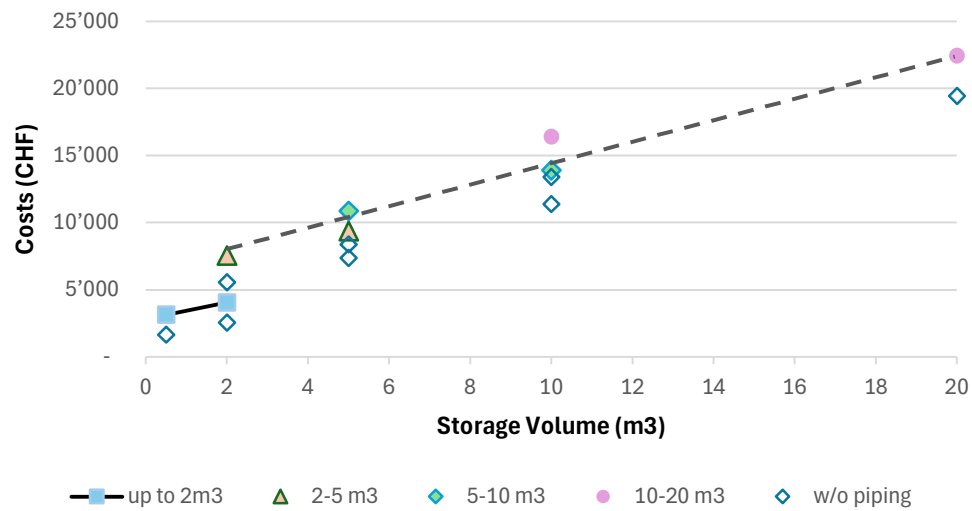


Figure 7: Investment cost functions for storage tanks up to 20 m³. The investment cost shows a discontinuity at 2 m³, reflecting the additional costs associated with on-site welding for larger storage tanks. The solid and dashed lines represent linear cost fits for storage volumes up to 2 m³ and above 2 m³, respectively. The markers show quoted storage tank costs for different volume ranges, while the white diamonds indicate storage tank costs excluding piping. Source: personal communication with a Swiss storage tank provider.

The costs of district heating (DH) pipelines depend on the nominal pipe diameter and the terrain in which they are constructed. For networks in a rural area, it is assumed that half of it is located on streets and half is not (but in fields etc.). The complete cost data for KMR pipes from DN20 to DN500, obtained from QM Thermische Netze (2025), is available in the Appendix. Since only DN20 to DN40 are used in the simulated Landiswil DHN, Table 3 includes only these pipe diameters.

CO₂ emissions are average values within the range of potential storage sizes, given that the emissions per liter vary with the differing sizes. Greenhouse gas emissions associated with biomass and natural gas are solely attributable to the fuels themselves and do not include any additional emissions resulting from the production of the heating center or pipes.

Table 3: Cost and greenhouse gas emissions assumptions of different parameters used for the biomass DHN.

	Costs		Greenhouse gas emissions	Source
Storage Tank (up to 2 m³)	2840 CHF	605 CHF/m³	0.44 kgCO ₂ -eq./liter	(Bundesamt für Energie, 2021; Swiss Federal Office of Energy SFOE, 2024)
Storage Tank (2 m³ to 20 m³)	7550 CHF	827 CHF/m³	0.38 kgCO ₂ -eq./liter	(Bundesamt für Energie, 2021; Institut für Solartechnik SPF, 2024)
DHN Pipeline, KMR DN20	842 CHF/m			(QM Thermische Netze, 2025)
DHN Pipeline, KMR DN25	889 CHF/m			(QM Thermische Netze, 2025)
DHN Pipeline, KMR DN32	981 CHF/m			(QM Thermische Netze, 2025)
DHN Pipeline, KMR DN40	1105 CHF/m			(QM Thermische Netze, 2025)
Biomass		0.054 CHF/kWh	0.011 kgCO ₂ -eq./kWh	(Bundesamt für Energie BFE, 2024; KBOB, 2022)

More values of general parameters not related to the biomass DHN are in the appendix. Cost assumptions specific to individual case studies are presented in the corresponding tables in Section 9.1.



4 Dynamic optimization with optihood

4.1 Energy system optimization framework

optihood³ (Dimri et al., 2023) is an open-source Python framework, developed at SPF, for the design and operation optimization of energy systems. It represents an energy system as a set of components namely, energy sources, sinks (or demands), energy conversion and storage technologies. These components could either be assigned to individual buildings or to the entire network. Buildings can additionally be coupled through thermal and electrical links, allowing locally produced heat and electricity to be shared across the network. Once the components have been defined, optihood uses the oemof solph⁴ package (which in turn uses pyomo⁵) to formulate the mathematical optimization problem as a mixed-integer linear program (MILP), i.e. a set of given parameters, constraints, decision variables and objective/target function. The resulting problem can be solved with any pyomo-compatible solver such as Gurobi, CBC or GLPK, with the goal of minimizing or maximizing the objective/target function.

The optimization objective can be either the minimization of total cost or the minimization of total greenhouse gas emissions. For cost minimization, both the annualized investment cost and the operation cost are accounted for; for emission minimization, optihood considers the operational emissions (for example from the use of biomass) together with the annualized embodied emissions of the installed conversion and storage technologies. Both objectives are implemented in the framework, which can be extended to further targets such as peak-load minimization.

In this project, optihood is used as the dynamic simulation tool to assess the potential of decentral storages in district heating networks. In contrast to a static sizing approach, optihood resolves the network operation at an hourly resolution over a full year (or the considered heating period) while simultaneously sizing the components. This makes it possible to capture the temporal interaction between heat demand, storage charging/discharging and grid bottlenecks, and therefore to quantify the trade-off between installing decentral storage on the one hand and re-dimensioning the heat source or the grid on the other. In order to carry out this analysis, we implemented two key extensions to the tool: a model for thermal grid representation, and a visualization module that makes the modelled network easier to inspect and to build. These extensions are described in the next two subsections.

4.1.1. Thermal grid

At the start of the project, a thermal grid was represented in optihood as a single node that balances the energy inflow(s) with the energy outflow(s). A schematic representation is shown on the left in Figure 8. This representation allows losses to be defined in a general way. For example, we could model that 20 % of the incoming energy is lost (this could be based on a fixed diameter and length of a DH pipe). The inflows to the thermal grid node originate either directly from energy sources (e.g. a biomass boiler) or from central thermal energy storage, while the outflows transfer this energy to individual buildings or to decentral storages. Furthermore, the cost of the thermal grid was included as a base investment cost and a cost per peak energy load to each output flow of the node.

In order to realize the objectives of this project, this simplified representation of thermal grid was extended by integrating the thermal grid model from the DHNx package⁶. DHNx describes district-heating pipes in terms of their length, diameter, roughness, maximum allowed pressure drop, and flow and return temperatures, and it includes a spatial representation of pipes, producers and consumers as shown in Figure 8 (right). Pipes are modelled as double pipes (feed and return), storage can be placed centrally (near a producer), within a branch or close to an individual consumer, and the network geometry can be

³ <https://github.com/SPF-OST/optihood>

⁴ <https://pypi.org/project/oemof.solph/>

⁵ <https://pypi.org/project/pyomo/>

⁶ <https://github.com/oemof/DHNx>



optimized on the basis of cost minimization. Heat demand can be specified either as a time series (e.g. hourly values over one year) or as a peak load per consumer together with a simultaneity factor.

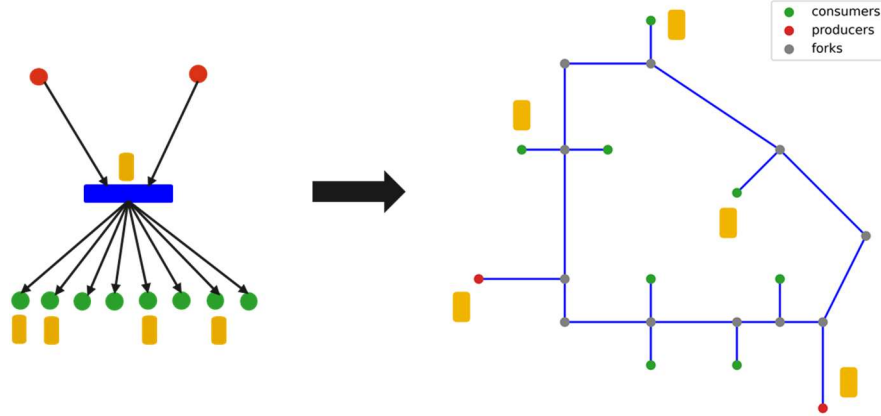


Figure 8: Extension of thermal grid model in the optihood optimization framework. Diagram on the left shows the representation of producers (red), consumers (green), storages (yellow) and thermal grid (blue) at project start; The implemented extension of thermal grid model is shown on right.

Hydraulic pre-calculations:

To use these DH pipes inside a MILP, each standardized pipe diameter (nominal diameter, DN) must be translated into a heat transport capacity (in kW) and into the associated investment cost (in CHF/m) and heat loss (in kW/m). For each DN this is done in three steps:

- i. The maximum permitted cross-sectional average flow velocity $v_{\max}$ is derived from the maximum allowed pressure drop (here 300 Pa/m), the inner pipe diameter, the roughness and the average fluid temperature T_{avg} .
- ii. The mass flow $\dot{m}$ is obtained from $v_{\max}$, the inner diameter d and the fluid density ρ (evaluated at T_{avg} with CoolProp⁷), as follows:

$$\dot{m} = v_{\max} \cdot \rho \cdot \pi \cdot \left(\frac{d}{2}\right)^2$$

- iii. The transport power P is computed from the mass flow and the difference between flow and return temperatures, ΔT , using:

$$P = \dot{m}(c_{p,f} \cdot T_f - c_{p,r} \cdot T_r)$$

here, T_f and T_r are the flow and return temperatures and $c_{p,f}$, $c_{p,r}$ the corresponding temperature dependent specific heat capacities.

Applying these relations to the standard pipe sizes yields, for each DN, the cost, the heat loss, the permitted flow velocity and the resulting transport capacity. The values used in this work (KMR pipes, flow/return temperatures of 80/50 °C, roughness 0.01 mm, maximum pressure drop 300 Pa/m) are summarized in appendix 9.1.

⁷ <https://pympi.org/project/CoolProp/>



Linearization of the cost and loss functions:

Within a MILP, both the pipe cost and the pipe loss must be expressed as linear functions of the optimization variable, i.e. of the pipe transport capacity P . As Figure 9 shows, neither the cost nor the loss is linear over the entire DN range. Both are therefore approximated by a piecewise-linear function with two segments: a steep segment for small pipes (DN 20-50) and a flatter segment for larger pipes (DN 65-150). The data points shown in the figure are based on QM Thermische Netze (2025).

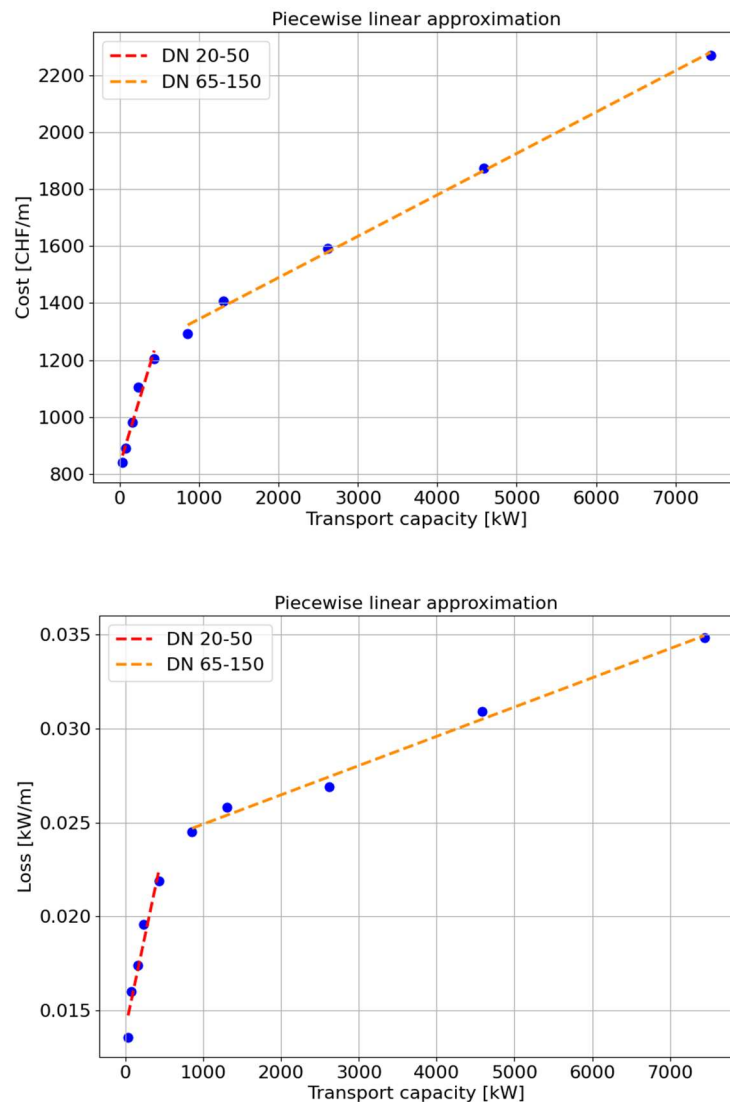


Figure 9: Piecewise-linear approximation of the pipe cost (top) and heat loss (bottom) as a function of the transport capacity. Blue dots are the calculated values per DN; the dashed lines are the two linear segments (DN 20–50 and DN 65–150). Source for cost and loss data points: QM Thermische Netze (2025).

The slope and intercept of each segment, obtained by a least-squares fit, are listed in

Table 4 and shown together with the data points in Figure 9. A pipe lifetime of 40 years and interest rate of 5% is assumed when annualizing the investment cost.



Table 4: Linear coefficients of the two-segment piecewise-linear approximation used for the pipe cost and the pipe loss.

Quantity	Segment	Slope	Intercept
Cost [CHF/m]	DN 20–50	0.923 (CHF/m)/kW	831
Cost [CHF/m]	DN 65–150	0.145 (CHF/m)/kW	1198
Loss [kW/m]	DN 20–50	1.95×10^{-5} (kW/m)/kW	1.40×10^{-2}
Loss [kW/m]	DN 65–150	1.56×10^{-6} (kW/m)/kW	2.34×10^{-2}

4.1.2. Visualization of optimization scenario

A visualization module was implemented in optihood to make the connections between components easier to understand when modelling an energy network. Previously, a network was defined through an input Excel file in which each sheet described one type of component and each row specified how a component was connected. Understanding or modifying a complete network therefore required parsing every sheet and cross-checking several rows, which was time-consuming and error prone.

The new module reads the input Excel file and generates an interactive graph (Figure 10) that shows all connections between the components together with the parameters set for each of them (for example the cost assumptions and the minimum and maximum allowed installation capacities). Clicking a component reveals its parameters. Each building is shown in a distinct color: for instance, a scenario can comprise one building that hosts a heat source and a thermal storage and two further buildings that each contain a storage and act as heat sinks with space-heating and domestic-hot-water demands. When the space-heating demand is modelled dynamically with a building model, the graph also reflects the possibility of rejecting excess heat in summer.

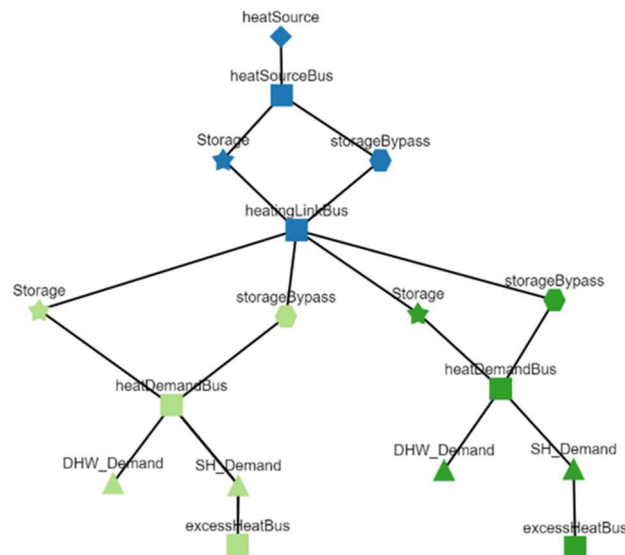


Figure 10: Graph network representing a scenario with three buildings (in blue, light green and dark green). The first building (blue) acts as a heat producer (heat source and storage) while the other two buildings act as consumers (storage and heat demand).

The implementation of thermal grid as well as the visualization module is publicly available in the optihood framework published on GitHub.



4.2 Idealized biomass district heating network

The optimization scenarios were built around a real biomass DHN located in Landiswil (described in Chapter 3). The network spans approximately 1.1 km and connects ten buildings, mostly residential, together with one school and one production warehouse, that are supplied by a central wood-chip biomass boiler and a central storage tank. The layout of the network, including the pipe and building numbering used throughout this chapter, is shown in Figure 11.

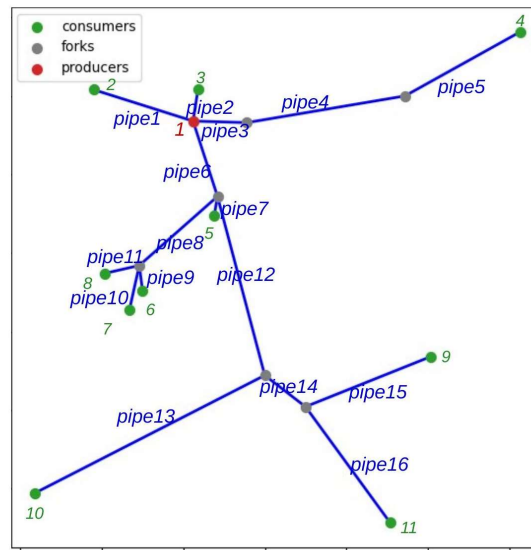


Figure 11: Topology of the Landiswil reference network. Node 1 (red) is the central producer; green nodes are the connected consumers (buildings 2–11) and grey nodes are pipe forks. Pipe numbers refer to the segments discussed in the text.

When the Landiswil DHN is modelled in optihood and the pipe diameters are optimized by minimizing the sum of investment and operation cost (CAPEX + OPEX), the resulting optimum diameters are considerably smaller than those actually installed (actual versus optimal: see Table 5). In other words, the real pipe network still provides sparse capacities to connect further consumers and is considerably over-dimensioned for the current demand, which would mask the effect of storage on grid bottlenecks. This result regarding the over-dimensioning of the reference network was further validated by modelling the same network in THENA. The resulting optimal pipe diameters matched perfectly between optihood and THENA, except for two minor mismatches: in one case optihood suggested DN25 while THENA suggested DN32, and in another case optihood suggested DN32 while THENA suggested DN25, corresponding to an overall match of 96%.

To create a baseline for evaluating the benefit of decentral storage, an idealized (“synthesized”) variant of the network was therefore derived: the annual heat demand was scaled up to about 0.93 GWh/a, the over-dimensioned pipe segments (pipes 6, 8, 12 and 14) were resized downwards, and the central heat source and storage were re-dimensioned to remove the excess reserves. The synthesized network keeps the topology of the reference network but represents a network which has reached its maximal connection density, so that the effect of decentral storage on peak loads becomes interesting.



Table 5: Actual and optimized pipe diameters of the Landiswil DHN (pipe locations, see Figure 11).

Pipe	Actual	Optimum	Peak Power (kW)
1	DN 32	DN 20	36
2	DN 32	DN 25	43
3	DN 40	DN 20	36
4	DN 40	DN 20	36
5	DN 25	DN 20	36
6	DN 63	DN 40	165
7	DN 63	DN 20	36
8	DN 63	DN 25	57
9	DN 25	DN 20	36
10	DN 25	DN 20	36
11	DN 32	DN 20	36
12	DN 50	DN 32	107
13	DN 32	DN 20	36
14	DN 50	DN 32	97
15	DN 32	DN 20	36
16	DN 40	DN 32	83

Table 6: Comparison between the peak load and the capacity of the connecting DH pipe for the connected consumers in Landiswil DHN. Buildings and pipes are labelled in Figure 11.

Building	Peak Demand (kW)	Connecting pipe	Pipe peak power (kW)	Ratio pipe peak/demand
2	7.4	pipe1 (DN20)	36	4.8
3	42.5	pipe2 (DN25)	76	1.8
4	10	pipe5 (DN20)	36	3.6
5	11.8	pipe7 (DN20)	36	3.0
6	8.8	pipe9 (DN20)	36	4.1
7	31.7	pipe10 (DN20)	36	1.1
8	13.4	pipe11 (DN20)	36	2.7
9	16.6	pipe15 (DN20)	36	2.2
10	6.3	pipe13 (DN20)	36	5.7
11	81.3	pipe16 (DN32)	157	1.9



4.3 Optimization results

The following results are based on dynamic optimizations performed on the idealized biomass DHN described in Section 4.2.

4.3.1. Comparison between central and decentral storage solutions

To quantify the benefits of decentralized storage, the idealized network was optimized under three different storage configurations with central and decentral storage solutions. The optimization target was to minimize the total annualized system cost, including the annualized investment costs of the storage units and the operational costs of the system. A biomass boiler of 350 kW capacity is used as the heat source in all the three cases. In each case, the installed storage volume was optimized either at the producer, at the individual buildings, or as a combination of both. For the mixed central/decentral configuration, a minimum central storage volume of 8.7 m³ was included, corresponding to the legally required buffer storage for the 350 kW biomass boiler, based on 25 L/kW installed boiler capacity. The following storage configurations were found to be the cost-optimum:

1. Only Central Storage: a single 18.2 m³ storage tank at the heat producer.
2. Central + Decentral Storage: An 8.7 m³ central storage tank, corresponding to the minimum buffer storage required for the 350 kW biomass boiler, supplemented by 800-1000 L of decentral storage in each building (around 9.5 m³ in total).
3. Only Decentral Storage: Decentral storage tanks of less than 2000 L in every building (about 18.2 m³ in total). This case is used as an analytical comparison of storage placement. For a real biomass boiler system, the legally required central buffer storage would still have to be installed.

Furthermore, the losses caused by the DH pipes amount to about 15 % annually and the resulting levelized cost of heat is around 0.14 CHF/kWh. The optimizations result in approximately the same total system storage volume of 18 m³, such that only the spatial distribution of the storage differs across these cases.

It should be noted that the cost of the central storage case depends on whether on-site welding is required. As shown in Figure 7, including or excluding welding-related costs leads to a visible difference in the upfront investment cost of storage tanks. In practice, a single central storage tank of around 18 m³ may be installed without on-site welding, depending on the available space and installation conditions at the heat producer. In that case, the central storage option would have a slightly lower upfront investment cost than assumed here. However, when this difference is annualized over the assumed 40-year storage lifetime, its contribution to the total annualized system cost becomes negligible and has practically no effect on the resulting LCOH.

Overall, these results show that the total cost-optimal storage volume and LCOH remain nearly unchanged across the three configurations. Although the upfront cost of central storage may be slightly lower if on-site welding is not required, this difference does not affect the LCOH when annualized costs are considered. Therefore, in the absence of network bottlenecks and excluding regulatory boiler-buffer requirements, the main difference between central and decentral storage lies primarily in the spatial distribution of storage rather than in the overall annualized system cost or required storage capacity.

However, decentral storage can provide an additional advantage when the network is constrained, as it can help alleviate local bottlenecks that cannot be addressed by central storage. In general, such bottlenecks can be resolved either by: (i) increasing the capacity of the limiting network or supply component, for example by replacing undersized pipes with larger diameters or by increasing the installed capacity of the limiting heat source technology, such as the central boiler or heat pump, or (ii) by installing decentral storage close to the constrained demand, thereby reducing peak loads on the affected part of the network.

To investigate this, a bottleneck in the piping was introduced by scaling the heat demand of Building 10 by 10%, 50%, 60%, 80%, and 100% (see Figure 12). The scaling of heat demand can be interpreted as



a simplified representation of connecting additional consumers at this location. The results compare two strategies for addressing the resulting bottlenecks: installing decentral storage near the affected demand and resizing the constrained network sections. The results show that addressing the bottleneck through pipe replacement leads to considerably higher additional investment cost compared to installing decentral storages. However, when the demand is increased by 100%, the bottleneck cannot be covered by decentral storages alone, and network resizing becomes necessary, as shown in Figure 12.

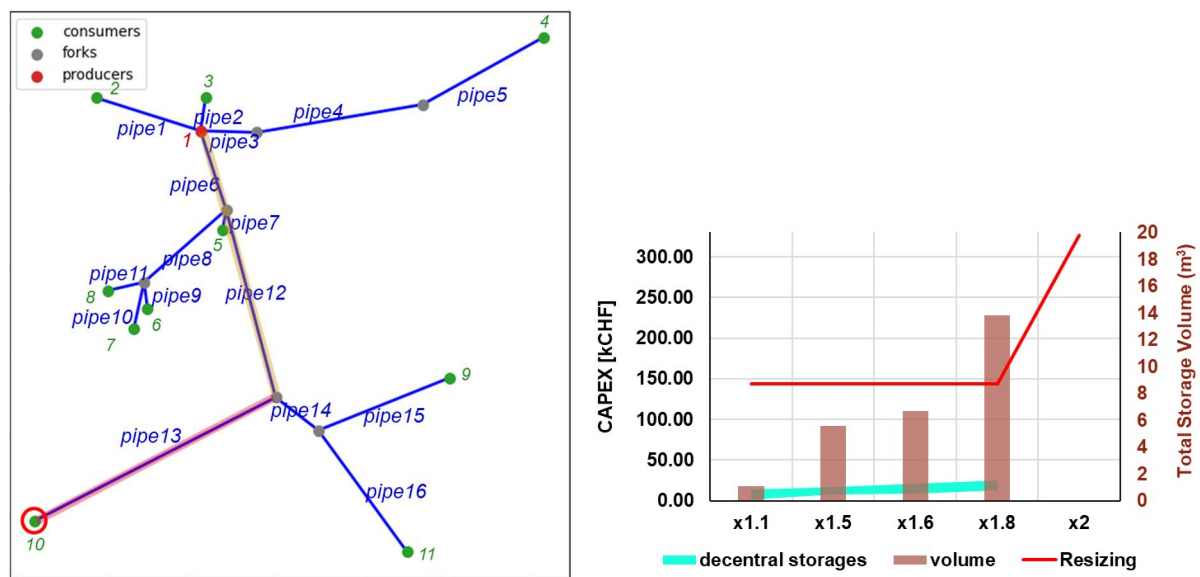


Figure 12: DHN scheme showing Building 10 and the network sections (pipes 6, 12 and 13) where bottlenecks are introduced, and the optimization results when the demand of Building 10 is increased gradually from 10% up to 100%.

4.3.2. Peak-load shaving using decentral storages

In order to quantify the peak-shaving potential of decentral storages, the idealized biomass DHN was simulated to find the optimal volume and placement of decentral storages with the goal of minimizing the peak power supplied by the heat producer. Charging and discharging of the storages was controlled by the optimizer, representing an ideal control knowing the entire future demand. The results therefore give an estimate of the maximal potential of decentralized storages, which real controllers can't exploit fully. Figure 13 presents and compares the results without and with decentral storages, and across decentral storages of different volumes.

When larger decentralized storages are permitted (e.g., 3.5 to 4 m³ in residential buildings, 6.5 m³ in the production facility, and 11 m³ in the school), the network experienced a maximum peak load reduction of 31%. The peak load dropped significantly from 464 kWp down to 318 kWp. Notably, achieving these massive peak reductions resulted in only marginal system cost increases ranging from 0.8% to 3.8%.

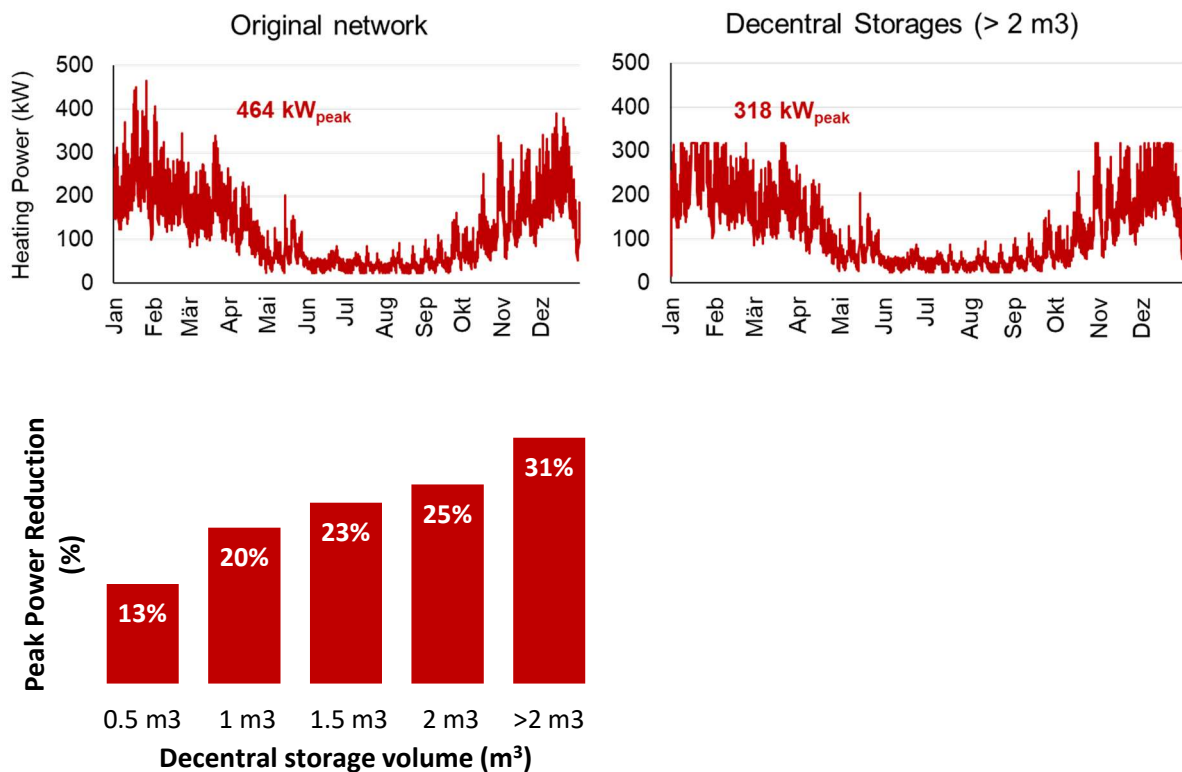


Figure 13: Peak power reduction achieved using decentral storages in the idealized biomass DHN.

The smoothing effect is shown in Figure 14, which compares the heat generation profile of the original network with that obtained when large decentral storages are available, over a representative cold period at the end of January. The decentral storages shave the pronounced demand peaks, which in the original network last several hours (up to 17 h in the coldest stretch), and shift this energy production in time, so that the heat source operates at a much flatter, lower output.

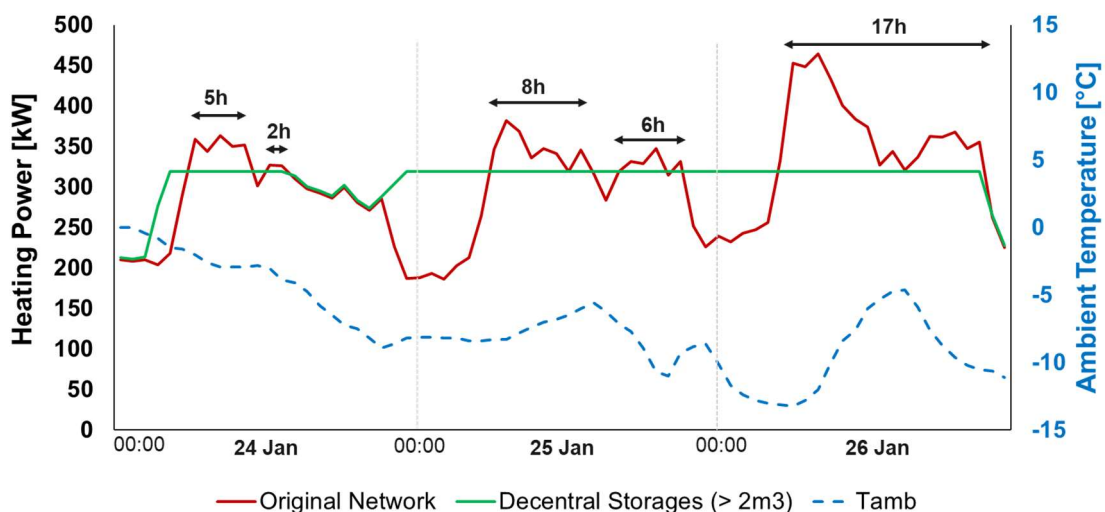


Figure 14: Peak power reduction and temporal shifting achieved using decentral storages of more than 2 m³ capacity in the idealized biomass DHN.



4.3.3. Integration of solar thermal energy

A further set of optimizations examined the decentralized coupling of a solar thermal field into the biomass network. The operational goal was to avoid firing wood during the summer months (June to August), so that the biomass can be conserved for the heating season and the boiler is not required to run in summer.

Three storage configurations were investigated for the integration of decentralized solar thermal heat: (i) central storage only, (ii) central storage supplemented by 5 m³ of decentral storage in each building, and (iii) central storage combined with larger decentral storages. The optimized capacities are shown in Figure 15. As the amount of decentral storage increases, the required central storage volume decreases substantially, from 135 m³ in the central-storage only case to 89 m³ and 22 m³ in the two mixed configurations. At the same time, the installed decentral storage volume increases from 0 m³ to 50 m³ and 121 m³, respectively. The required solar thermal collector capacity also decreases slightly across the three configurations, from 730 m² to 683 m² and 607 m², indicating that larger decentral storage improves the utilization of locally integrated solar heat.

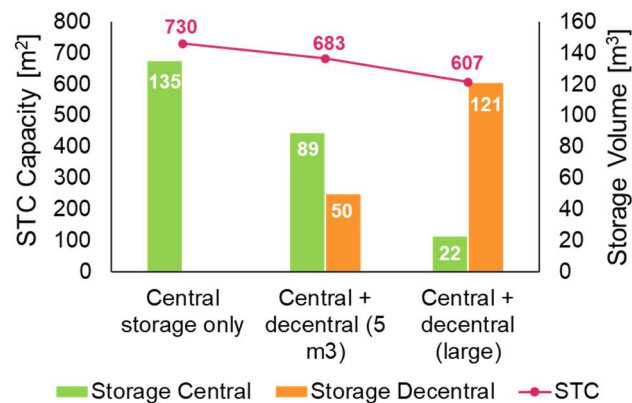


Figure 15: Optimized capacities of solar thermal collector (STC) and storage tank in the idealized DHN for the three storage configurations.

Integrating the solar thermal field reduces the non-renewable greenhouse gas emissions of the network by about 21-22 % relative to the case without solar thermal. For biomass, only the non-renewable emissions associated with its supply chain are considered, using an emission factor of 11 g CO₂eq/kWh; biogenic CO₂ from combustion is not included in this analysis. The emission reduction is accompanied by an increase in total cost of roughly 20-23 %, with only minor differences between the three storage configurations. The cost and emission results for the solar thermal scenarios are shown in Figure 16.

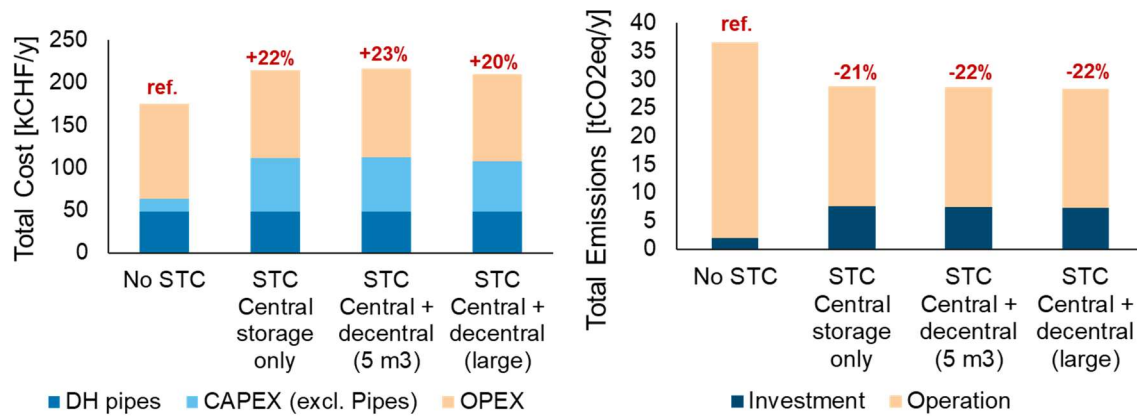


Figure 16: Total annual cost (left) and total annual greenhouse gas emissions (right) of the idealized DHN without and with a solar-thermal field, for the three storage configurations.

The optimization successfully demonstrated that decentralized solar heat could adequately cover the summer heat demand. The system achieved a collector field yield of 413 kWh/m², with a peak output of 50 kW, leading to a notable reduction in non-renewable greenhouse gas emissions for the network.



5 Practical planner toolchain: PeakAnalyser and THENA

While dynamic optimization with optihood provides powerful, in-depth system analysis, it relies on complex Python-based mathematical solving that can be time-consuming when setting up yearly simulations. Furthermore, in depth mathematical and programming knowledge is needed to utilize the framework. To address the day-to-day needs of network planners, a more iterative, manual, and user-friendly toolchain was developed. This workflow (Figure 17) combines the visual PeakAnalyser GUI (Section 5.1) for demand peak analysis with the THENA Excel tool (Section 5.2) for network dimensioning and, as a newly developed feature, sizing of decentral storage tanks.

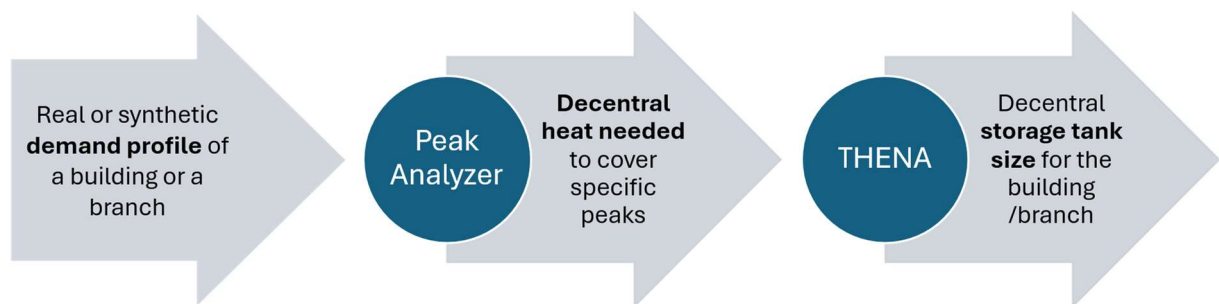


Figure 17: Working steps to define the needed size of decentral storage tanks based on demand profiles with the two tools, PeakAnalyser and THENA.

The tools can be used as follows: The measured or synthetic data of a heat demand of a building or a network branch of interest over a certain time span (e.g. during winter) is loaded into the PeakAnalyser tool. In the PeakAnalyser, critical peaks can manually or automatically be detected with respect to a chosen maximum capacity (e.g. of a network pipe) and the amount of heat in kWh needed to cover these peaks is calculated by the tool. This information (heat in kWh) is entered into THENA, where, together with the information about the flow and return temperature in the network, the needed volume of a storage tank to cover the peaks is calculated. Details about the development and the use of the tools are explained in the following sections.

5.1 Peak capacity analysis with PeakAnalyser

The PeakAnalyser (Figure 18) is a Python-based GUI-application developed within the project to visualize aggregated heat demand profiles and analyse the feasibility of peak load shifting. The tool is designed to evaluate whether demand peaks that exceed a given power limit, for example the capacity of a critical network pipe, can be shifted to earlier time periods by pre-charging decentralized storage at the customer side. In addition, the demand profile can be scaled to create hypothetical increased demand scenarios at a network branch, for example to assess possible extensions of the existing network.

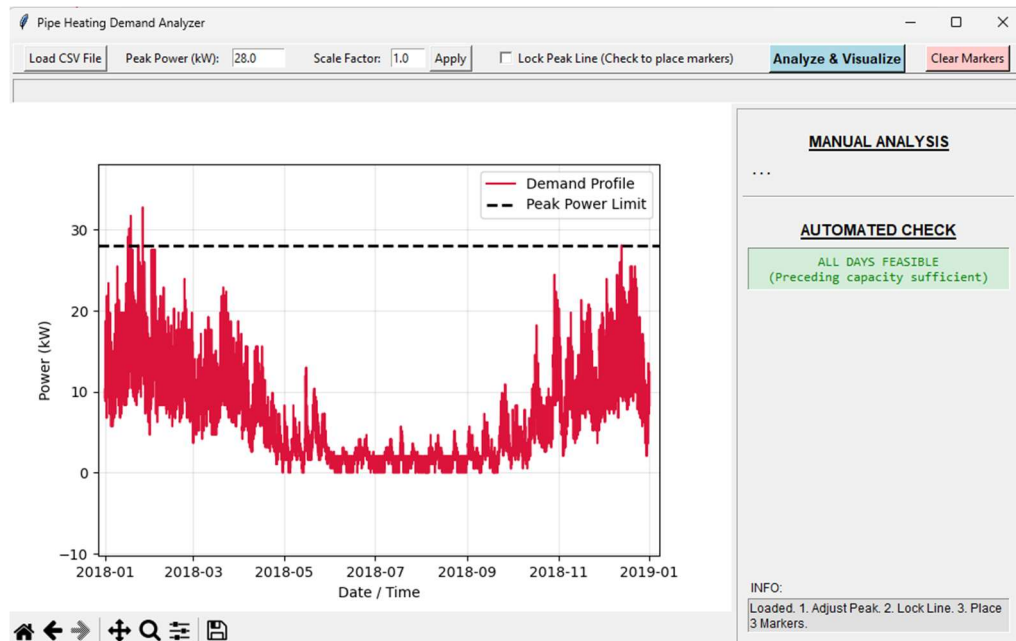


Figure 18: User interface of the PeakAnalyser showing a loaded demand profile and a selected peak power limit. The tool is used to assess whether demand peaks in critical network sections can be reduced by pre-charging decentralized storage before the peak occurs at the customer.

Key features of the PeakAnalyser include:

- Interactive visualization of heat demand time series.
- Peak-load analysis based on a user-defined power limit, for example the capacity limit of a critical pipe.
- Scaling of the demand profile to represent hypothetical demand scenarios, such as increased heat demand due to future network expansion.
- Automated daily feasibility check to determine whether sufficient unused capacity is available before each peak event to charge decentralized storage and cover the demand exceeding the peak limit.
- Manual peak-shifting analysis for selected periods using markers, where the first and second markers define the available storage-charging period, and the second and third markers define the peak period over which excess demand must be shifted.

The main function of the tool is to compare a demand profile with a user-defined peak power limit. For all periods in which the demand exceeds this limit, the tool calculates the excess energy that would need to be covered by decentralized storage. The automated check performs this assessment on a daily basis and identifies days for which the available preceding capacity is insufficient to fully compensate the demand above the defined peak limit. These days can then be inspected in more detail using the manual analysis mode.

Figure 19 shows the graphical analysis for customer #10 in the Landiswil network for the period from 15 January 16:00 to 17 January 04:00. The red line shows the heating demand profile, while the black dotted line represents the selected peak power limit of the critical network pipe. The numbered crosses define the periods used for the manual calculation: the first and second crosses mark the time window in which decentralized storage can be charged using the available capacity below the peak limit, while the second and third crosses define the subsequent peak period during which the stored heat is



required. The shaded blue area above the peak limit indicates the excess demand that would need to be supplied from decentralized storage. The tool then compares this excess demand with the available charging capacity in the preceding period (defined by the first and second markers).

The corresponding numerical results are shown in Figure 20. The tool reports the energy above the peak limit, the available charging capacity before the peak, and characteristic values of the peak such as the maximum exceedance in kW. The automated results indicate the days with uncovered peaks, while the manual results provide a detailed calculation for the user-selected period. This combination allows users to first identify critical days automatically and then examine selected peak events in more detail.

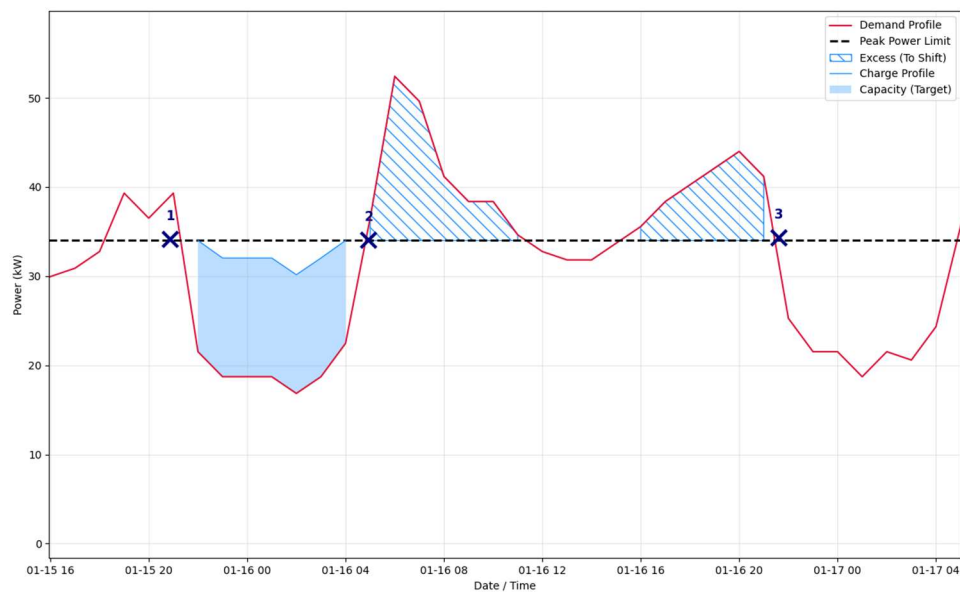


Figure 19: Peak load investigated with the tool PeakAnalyser. The example shows the heat demand profile in kW, the selected peak power limit of the critical network pipe, the manually defined analysis periods, and the resulting amount of heat in kWh that would need to be stored in decentralized storage to cover the subsequent demand peak. The example refers to customer #10 in the Landiswil network for the period from 15 January 16:00 to 17 January 04:00.

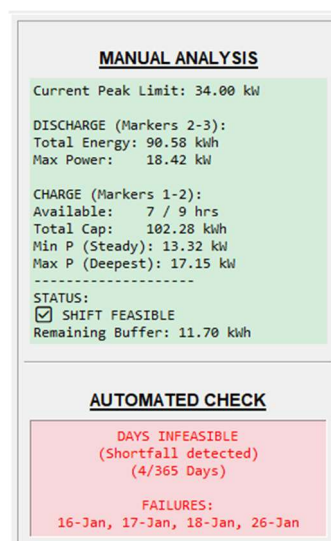


Figure 20: Manual and automated analysis results from the tool PeakAnalyser for the graphical analysis shown in Figure 19. The tool quantifies the energy above the peak limit and the available charging capacity in kWh, provides peak characteristics in kW, and flags periods with uncovered peaks for further manual analysis.



The PeakAnalyser requires a CSV input file containing a timestamp column and a power demand column. The tool has been currently used and tested for hourly demand profiles. Users can load a demand profile, define or adjust a peak power limit, optionally scale the demand profile to represent different demand scenarios, and perform either automated or manual peak-shifting analysis. In the manual mode, three points are selected on the time series to define the charging period and the subsequent peak event. PeakAnalyser is available as freeware and can be downloaded from the tool's website⁸, which also provides an example CSV input file, step-by-step usage guide and instructions.

5.2 Sizing of a network and a decentral storage tank with THENA and PeakAnalyser

To demonstrate the practical use of the PeakAnalyser and THENA toolchain, the following workflow was applied to the idealized biomass network Landiswil defined in Section 4.2.

THENA⁹ is an Excel-based user tool developed by Verenum AG. Its primary aim is to enable the technical and economic assessment of heat distribution networks. The tool has been specifically adapted within this project to include the use of decentral storage tanks while sizing the district heating pipes and the overall thermal network.

The modelling of a network in THENA needs to be based on a network plan that must be prepared in advance. Such a preparation is shown in Figure 21, where it is important to number all the branches and define the daily average heat load at design temperature for all the customers. In addition to this, it also requires following information for each numbered branch: nominal diameter, pipe type, insulation thickness, length, laying situation, section of worst-case customer (1/0) and optional Zeta-Values for pipe bends or armatures within the individual network sections.

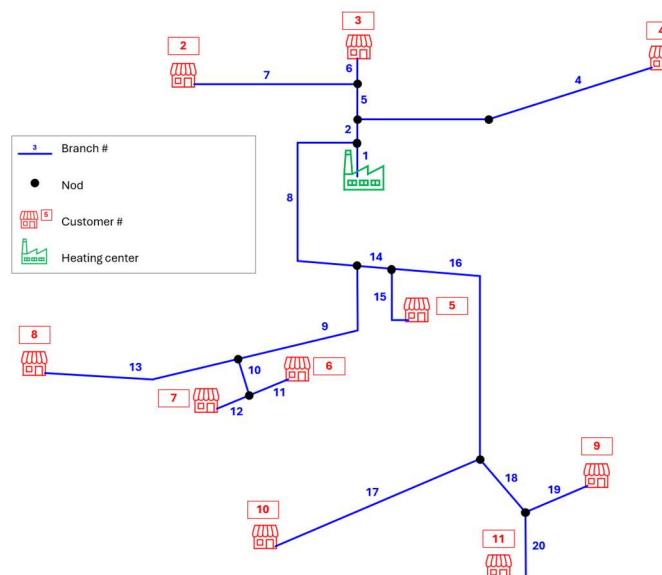


Figure 21: Network plan for Landiswil with numbered branches and customers.

Based on this information, the network can be set up in THENA. With all the implemented general information, it is possible to have first results for the dimensioning of the pipes, costs and pressure situation for the critical point in the network (see Appendix 9.2), which is usually at the most distant customer.

⁸ <https://spf-ost.github.io/PeakAnalyser-releases/>

⁹ <https://qmthermischenetze.ch/dokumente-tools/>



The results in THENA for the “idealized” network Landiswil according to Section 4.2 show that the network is well dimensioned (indicated in THENA with highlighted field in green as shown in Figure 22).

Results of line sections

Results of line sections

Project: DistrictGrids
Variant: WV Landiswil
Characteristic values for pipe types according to QM district heating (default values)
Input parameter (E3) according to QM district heating (default value)
Project manager: Stefan Thalmann
Date: 24.03.2026

THENA V1.34.0 - DistrictGrids_CWP
Leistungsoptimiert, Originale Leitungsquerschnitte
Gebäude 10 (Strang 20)

Values taken from industry input data	Line sections	1	2	3	5	16	17	18
Transportable thermal power	kW	500	138	35	222	34	188	
Type of pipe	—	KMR	KMR	KMR	KMR	KMR	KMR	
Nominal diameter	DN	65	32	20	40	20	40	
Insulation thickness	—	2	2	2	2	2	2	
Length of route	m	1	1	5	160	130	30	
Laying situation	—	Flur	Flur	Flur	Flur	Flur	Flur	
Coefficient of resistance of the elements embedded in the section	—	0	0	0	0	0	0	
Connecting pipe	No = 0 Yes = 1	0	0	1	0	1	0	
Line section worst case consumer	No = 0 Yes = 1	1	0	0	1	0	1	
Position of pressure build-up	No = 0 Yes = 1	0	0	0	0	0	0	
Evaluation								
Optimum nominal diameter	—	65	32	20	40	20	40	
Branch sizing	—	ok	ok	ok	ok	ok	ok	
Deviation from optimum (in number of nominal diameters)	—	0	0	0	0	0	0	
Pressure loss per metre of pipe	Pa/m	127.2	270.3	27327.5	314.8	304.6	231.9	
Hydraulic utilisation rate	%	39%	82%	8.99%	95%	92%	70%	
Visualisation								

Figure 22: Extract of the results for each line section (1, 2, ...) in THENA for the optimized DHN of Landiswil.

After the basic preparation of the Landiswil DHN in THENA, a specific example case is introduced to demonstrate the analysis. In this case, customer #10 is assumed to have an increased peak demand, represented by scaling its original demand profile by a factor of 1.8. This could, for example, correspond to a future building extension at building #10. The affected network pipes are highlighted in green in Figure 23. The scaling factor of 1.8 was selected based on the results presented in Section 4.3.1 (see Figure 12), where a demand increase by a factor of 1.8 represented the highest scaling level for customer #10 that could still be supplied using decentralized storage. Increasing the scaling factor further to 2.0 resulted in no feasible solution with decentralized storage alone, leaving network resizing as the only feasible option.

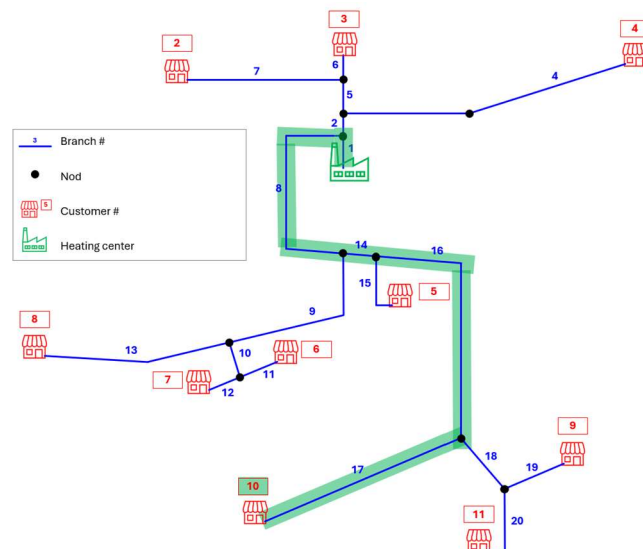


Figure 23: Network plan for Landiswil with highlighted branches from the heating centre to the customer in green, where the decentralized storage tank will be placed, for this case customer #10.

With the increased peak demand of building #10 and without decentral storage in the building, the line sections #16 and #17 (Figure 23 and Figure 24) are too small respectively have a specific pressure loss which exceeds the defined threshold value, in this case 330 Pa/m.



Results of line sections									
Project: DistrictGrids									
Variant: WV Landiswil									
Leistungsoptimiert, Originale Leitungsquerschnitte									
Gebäude 10 (Strang 20)									
Project manager: Stefan Thalmann									
Date: 24.03.2026									
THENA V1.3d_DezentGrids_CHF									
Characteristic values for pipe types according to QM district heating (default values)									
Input parameter (E3) according to QM district heating (default value)									
Values taken from industry input data									
Transportable thermal power	kW	518	138	35	240	52			
Type of pipe		KMR	KMR	KMR	KMR	KMR			
Nominal diameter	DN	65	32	20	40	20			
Insulation thickness		2	2	2	2	2			
Length of route	m	1	1	5	160	130			
Laying situation		Flur	Flur	Flur	Flur	Flur			
Coefficient of resistance of the elements embedded in the section		0	0	0	0	0			
Connecting pipe	No = 0 Yes = 1	0	0	1	0	1			
Line section worst case consumer	No = 0 Yes = 1	1	0	0	1	0			
Position of pressure build-up	No = 0 Yes = 1	0	0	0	0	0			
Evaluation									
Optimum nominal diameter		65	32	20	50	25			
Branch sizing		ok	ok	ok	too small	too small			
Deviation from optimum (in number of nominal diameters)		0	0	0	-1	-1			
Pressure loss per metre of pipe	Pa/m	135.9	270.3	327.5	364.6	665.6			
Hydraulic utilisation rate	%	41%	82%	99%	110%	202%			
Visualisation									

Figure 24: Extract of the results in THENA, showing an undersizing of pipes #16 and #17 (see yellow fields).

The PeakAnalyser can now be used like introduced in Section 5.1 to find the specific peak load which should be covered by a decentral storage tank. The supply limit (dashed black line in Figure 25) is given by the pipe capacity of the most critical pipe (here: pipe #17 with 34 kW). The graphical analysis of the time series of the heat demand of building #10 in the PeakAnalyser gives as result:

- Absolute peak power of 52.4 kW
- Energy demand in this period that must be shifted in time (from the blue shaded area to the blue area) using a decentral storage of 90.58 kWh. This represents the minimum required storage capacity in kWh.



Figure 25: Determination of the heat that needs to be stored decentrally with the purpose to eliminate the analysed peak in the network using the PeakAnalyser Tool. Example from 15 January to 17 January for customer #10 of the Landiswil DHN with highlighted information that is needed for the further design steps in THENA.

The results of the PeakAnalyser are fed into THENA. By entering the peak load capacity and the total energy demand of the peak, users can quickly see how the pipe diameters, and consequently, the capital expenditures (CAPEX) and network losses are influenced and, in the best case, can be optimized. This



can be beneficial in a planning stage or for an existing network for optimization and extension. Importantly, the tool remains easy to use and comprehensible, functioning entirely without complex macros.

All required input values must be specified in folder "E2_Teilstränge" in THENA (Figure 26):

1. Branch line from heating center to the customer with a decentralized storage tank (Column P): Each line that fulfils this condition is set to 1, all others are set to 0.
2. Absolute peak power e.g. hourly peak value (Column Q): Maximum value for the peak in kW (e.g. from the Tool PeakAnalyser or some other source).
3. Energy demand at peak load (Column R): Total energy demand of the peak in kWh (e.g. from the Tool PeakAnalyser or some other source).
4. Based on the calculated minimum required storage volume (Column U): design volume of the decentral storage tank (Column V) decentralized storage tank in m³.

The following output values are for additional information:

- Column S - Duration of peak in hours (hourly peak value)
- Column T - Relative peak power (e.g. hourly peak value): Difference between peak value (column Q) and connection capacity (column B) in kW.
- Column W - Energy content of storage (decentralized): result given in kWh

After defining the volume of the decentral storage, the affected pipes still stay marked with a warning in THENA (as shown in Figure 24). However, with the information of the volume of the decentral storage and of the relative height and the duration of the peak, a planner can assess the effect and the possible prevention of the analysed peak in the network branch.

A	B	C	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	
Input distribution network																			THEMA V13.4_DecentralGrids_GH		
Assumptions for calculations																			Project: DistrictGrids		
Characteristic values for pipe types according to QM district heating (default values)																			Variant: WV Landiswil		
																			Leistungsoptimiert, Originale Le		
																			Gebäude 10 (Strang 20)		
																			Project manager: Stefan Thalmann		
																			Date: 24.03.2026		
Input range for sub-loops													Input range for decentralised storage								
Line sections	Connection capacity		Thermal transmission capacity of branch lines	Type of pipe	Nominal diameter	Insulation thickness	Length of route	Laying situation	Line section worst case consumer	Position of pressure build-up	Coefficient of resistance of the elements embedded in the section	Input data check	Branch line from heating plant to decentralised storage (peak)	Absolute peak power (e.g. hourly peak value)	Energy demand at peak load	Duration of peak power (hourly peak value)	Relative peak power (e.g. hourly peak value)	Minimum required storage volume (decentralised)	Planned storage volume (decentralised)	Energy content of storage (decentralised)	
-	kW	OR Connection line e.g. 3,5																			kW
1		2,8	518,1	KMR	65	2	1,0	Flur	1	0	0	0	1	1							
2		3,5	137,6	KMR	32	2	1,0	Flur	0	0	0	0	1	0							
3		4	32,0	KMR	20	2	105,0	Flur	0	0	0	0	1	0							
4	32,0		32,0	KMR	20	2	90,0	Flur	0	0	0	0	1	0							
5		6,7	105,6	KMR	32	2	30,0	Flur	0	0	0	0	1	0							
6	72,3		72,3	KMR	25	2	5,0	Flur	0	0	0	0	1	0							
7	33,3		33,3	KMR	20	2	33,0	Flur	0	0	0	0	1	0							
8		9,14	380,5	KMR	50	2	85,0	Flur	1	0	0	0	1	1							
9		10,13	105,0	KMR	32	2	105,0	Flur	0	0	0	0	1	0							
10		11,12	70,1	KMR	25	2	5,0	Flur	0	0	0	0	1	0							
11	35,2		35,2	KMR	20	1	10,0	Flur	0	0	0	0	1	0							
12	34,9		34,9	KMR	20	2	10,0	Flur	0	0	0	0	1	0							
13	34,9		34,9	KMR	20	2	135,0	Flur	0	0	0	0	1	0							
14		15,16	275,5	KMR	50	2	5,0	Flur	1	0	0	0	1	1							
15	35,4		35,4	KMR	20	2	5,0	Flur	0	0	0	0	1	0							
16		17,18	240,1	KMR	40	2	160,0	Flur	1	0	0	0	1	1							
17	34,0		52,4	KMR	20	2	130,0	Flur	0	0	0	0	1	1	52,4	90,6	4,9	18,4	2,64	3,0	102,8
18		19,20	187,7	KMR	40	2	30,0	Flur	1	0	0	0	1	0							
19	33,2		33,2	KMR	20	2	70,0	Flur	0	0	0	0	1	0							
20	154,5		154,5	KMR	40	2	100,0	Flur	1	0	0	0	1	0							

Figure 26: Input data and definition of the whole network of Landiswil with THENA with the added information for the peak and decentralized storage tank.

In the example shown in Figure 26, the peak load of 52.4 kW occurs only for a given time (4.9 h, see column S). The exceeding pressure losses in line sections #16 and #17 can be reduced to the accepted threshold installing a decentral storage with a minimum volume of 2.64 m³.



6 Case Studies

The methods described in the previous chapters were applied to two district heating networks (DHN) in Switzerland in order to assess, under realistic conditions, the potential of decentralized thermal energy storages (TES) for reducing thermal power peaks and, where relevant, for influencing the sizing of the network pipes. The two case studies are the DHN of Wallisellen, which is currently in the planning stage, and an existing DHN in Switzerland. In both cases, the dynamic optimization tool optihood was used to quantify the peak-shaving potential of decentralized storages.

6.1 Case Study 1: Wallisellen District Heating Network

The first case study concerns a district heating network (DHN) in Wallisellen that is currently being planned by die werke versorgung wallisellen ag. As pipe diameters are not yet fixed for this case study, only the dynamic optimization tool optihood was applied. The objective was to minimize the thermal power peaks in the network by identifying the optimal location and sizing of decentralized storages from a system perspective.

6.1.1. Description of the case study

The district heating network (DHN) of Wallisellen, as currently planned, consists of a centralized heat pump (HP) and a borehole field that acts as a seasonal thermal energy storage, both located at the energy centre in the west of the city. Additionally, waste heat from a nearby incineration plant (KVA) is available between May-September in the east of the city. In these months, the heat demand can be entirely covered by the waste heat. Moreover, the remaining waste heat is used to regenerate the borehole field. The central HP can be operated either with ground-source (extraction from the borehole field) or air-source (from the ambient air). Additionally, there is a biogas boiler planned at the energy centre to cover peaks. There are 272 buildings which are planned to be connected to the DHN. Due to the complexity of the resulting optimization problem, it was not possible to model the entire network in detail within the optihood tool. As a result, we decided to simplify the optimization problem by aggregating the buildings into clusters based on the service area (German: Versorgungsgebiet). Figure 27 shows the aggregated DHN modelled in optihood. The 272 buildings were, therefore, reduced to 30 building clusters numbered as nodes from 2 to 31. The number of buildings within each cluster are shown in Figure 28. Within optimizations, a decentral storage could potentially be located at any of these nodes and would therefore represent a decentral storage shared by a building cluster. Node 1 represents the energy centre (EZ in Figure 27), consisting of the central heat pump (HP) and biogas boiler, and the borehole seasonal thermal energy storage (BHE in Figure 27). The network additionally models waste heat from the nearby incineration plant (KVA in Figure 27) at Node 1. In the real situation, the waste heat source is connected at fork 1 (on the left) in Figure 27. However, for the sake of simplicity in modelling, the waste heat is modelled at the energy centre (EZ) or node 1 within this study. This is done to avoid that the optimizer charges the decentral storages with the waste heat. This would lead to a marginal difference in the pipe losses during summer operation of district heating and neglect of pipe losses while regenerating the borehole field. However, since it does not affect the winter operation and the goal was not to optimize pipe dimensions but to minimize peaks, this simplification is not expected to influence the key outcomes of the study.

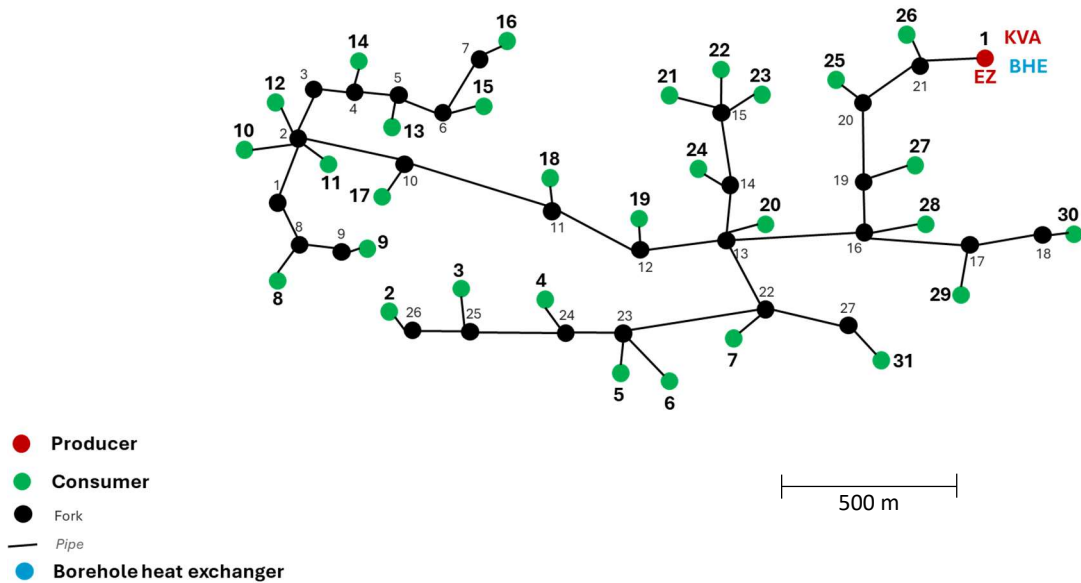


Figure 27: Aggregated district heating network (DHN) modelled in optihood. Each consumer node (in “green”) represents a cluster of buildings. The producer node (in “red”) is numbered 1, followed by consumer nodes in sequence up to 31. The fork nodes (or T-pieces) are numbered separately and are drawn in black.

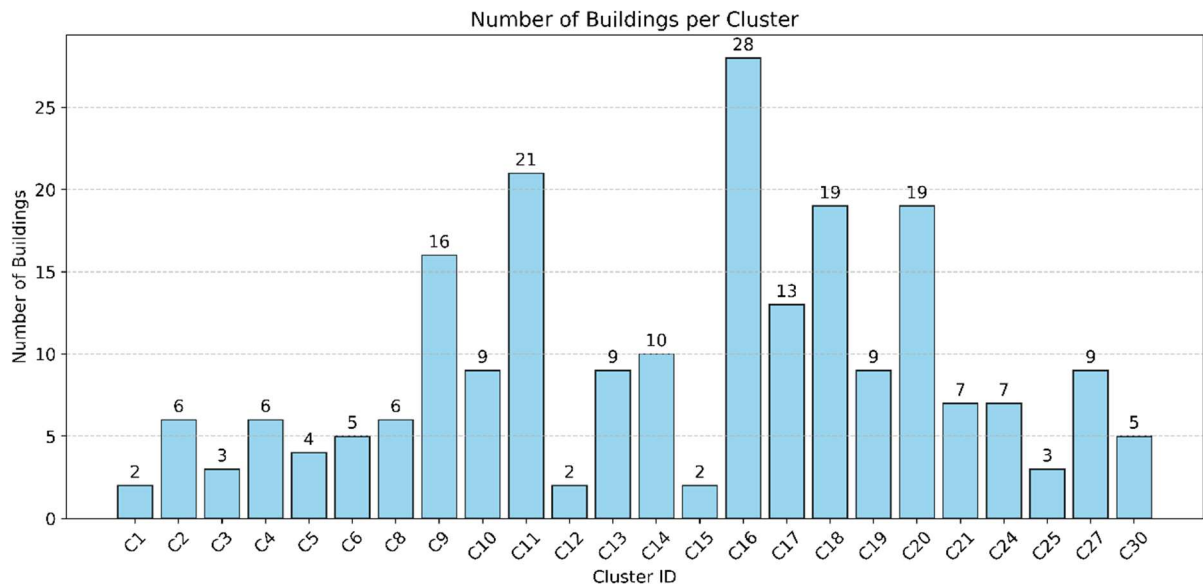


Figure 28: Number of buildings aggregated within each cluster modelled within the optihood tool.

In order to simulate the DHN, we needed to input the heating demand profiles of each building cluster. Since real measurement data with high temporal resolution is not available, we generated hourly heating demand profiles by scaling the standard profiles from nPro tool¹⁰. The nPro tool provides standard consumption profiles based on the building’s usage type and construction year. These standard hourly profiles were then scaled, to match the annual heating demand based on the available gas consumption data, and aggregated to prepare the demand profile of each cluster. Figure 29 shows the yearly heat demand of each building cluster.

¹⁰ <https://www.npro.energy/>

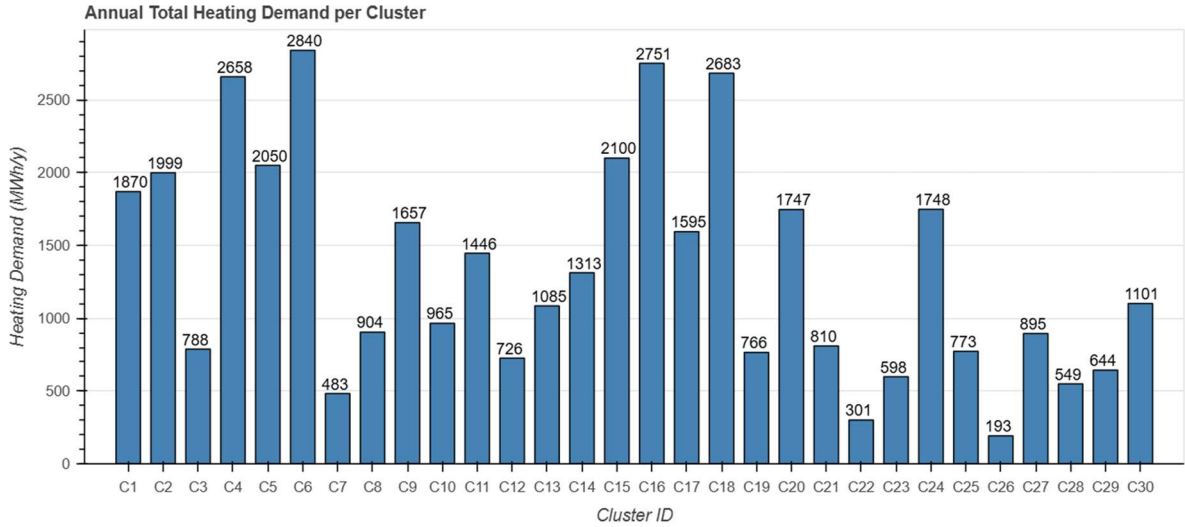


Figure 29: Aggregated heat demand, including space heating and domestic hot water consumption, of the buildings within each cluster.

To model the aggregated DHN in the optihood tool, in addition to aggregating the buildings into clusters, the DH pipes of each cluster need to be aggregated. These include the main transport pipes of the DHN as well as the pipes which connect these transport pipes to the individual buildings within each cluster. Pipe length and diameter are based on planning data from die werke versorgung wallisellen ag and not further optimized by optihood. As described in Section 4.1.1, the modelling of the DH pipes uses the nominal diameter (DN) of the pipe to calculate the permissible maximum energy flow and the heat losses incurred across the length of the pipe. The aggregated model should, therefore, reflect the maximum flow capacity and the total heat losses across the individual DH pipes. The equivalent nominal diameter (DN_{eq}) of an aggregated pipe is calculated as follows to model the maximum flow capacity of the DH pipe:

$$DN_{eq} = \max(DN_i)$$

where, DN_i represents the nominal diameter of the individual DH pipe i . The maximum is calculated across all the DH pipes to be aggregated.

The equivalent length (L_{eq}) of an aggregated pipe is calculated to preserve the physical surface area of the original pipe network, to account for the total heat losses (heat losses $\sim$ surface area).

$$DN_{eq} \cdot L_{eq} = \sum_i DN_i \cdot L_i$$

It is worthwhile to note that aggregating these losses would result in a conservative assumption, where we overestimate the losses within a building cluster. In the original network, heat delivered to a given building does not necessarily pass through all pipes within the cluster; therefore, assigning the aggregated losses to the cluster may overestimate the actual distribution losses. However, since the clustering is performed spatially within a limited service area, the DH pipes being aggregated cover only relatively short local distances. The resulting approximation is therefore considered reasonable for representing the aggregated DHN.

The objective of this study is to investigate the potential of decentral storages in minimizing the peak heating demand of the DHN, and as a result the consumption of biogas. The pipe lengths and diameters are assumed to be consistent with the DHN plan provided by die werke versorgung wallisellen ag, and are therefore, not optimized within this study.

We compare the following scenarios with and without decentral storages in the building clusters:



- Baseline scenario without decentral storages
- Peak minimization using decentral storages (cost of peak as 5 CHF/kW, 10 CHF/kW and 100 CHF/kW)

The peak cost values used in this analysis are not intended to represent specific tariff structures or measured market prices. Instead, they are introduced as a sensitivity parameter to investigate how different levels of economic incentive for peak reduction influence the operation and sizing of decentral storage within the building clusters. The selected values of 10 CHF/kW, 100 CHF/kW, and 1000 CHF/kW represent low, medium, and high peak-penalty cases, respectively.

6.1.2. Energy system modelling and assumptions

The modelled energy system in the Wallisellen case study consists of a central HP of 8 MW_{thermal} capacity (ground- and air-source), biogas boiler, waste heat, borehole field (ca. 105 m x 68 m, i.e. 17.8 GWh/y) and decentral storages. In order to capture the non-linear dynamics of the borehole field effectively, we base the optimisation models on the non-linear simulation models from the RegEWS project¹¹. The HP is modelled using two separate components namely, an air-source heat pump (ASHP) and a ground-source heat pump (GSHP), wherein at a given time only one of the two could operate. The availability of these HPs depends on the ambient air temperature. For ambient temperatures below 3°C, the GSHP is used, otherwise the ASHP is used. The coefficient of performance (COP) of the two heat pumps is represented by hourly varying COP values obtained from the RegEWS simulation model. Waste heat from the incinerator (KVA) is modelled as a heat source, limited to a maximum power of 12 MW and availability only from May until September. The waste heat can be used either to supply the demand directly (when available) or to regenerate the borehole field. The price and availability assumptions made for the modelled energy sources are summarized in Table 7.

Table 7: Price assumptions of different energy sources considered within the Wallisellen case study (source: die werke versorgung wallisellen ag).

Source	Price	Availability Restrictions
Biogas	12 Rp./kWh	-
Electricity	20 Rp./kWh	-

The priority order of supplying the demand by using first the waste heat (when available), then the HPs and at last, biogas boiler only for covering peaks which cannot be met using the HP alone, is automatically respected by the optimizer in simulations, due to the difference in the prices (Table 7) and therefore, does not need to be modelled separately.

The borehole field is modelled as a combination of a heat source (for extraction) and a heat sink (regeneration), while respecting the annual balance for injection and extraction to/from the field. The annual injection and extraction limits are pre-calculated using the detailed simulation model from the RegEWS project. Furthermore, we pre-calculate maximum hourly power injection and extraction limits based on the RegEWS simulation model as follows:

- Maximum power injection does not increase the outflow temperature of the field by over 70°C.
- Maximum power extraction without the average borehole inflow and outflow temperature falling below 1°C (including a safety buffer around the absolute limit of -1.5°C).

The capacity limit for decentral storages per cluster were defined to a maximum of 80L/kW of peak heating demand of the cluster.

¹¹ RegEWS - Feasibility Study on Reducing the Land Area Requirements of Large Borehole Thermal Energy Storage Fields for Thermal Networks: see project webpage on www.ost.ch/spf/regews



6.1.3. Results

Figure 30 shows the simulation results with energy flows from different conversion technologies, energy demand, DHN losses and borehole field injection/extraction for the cases without and with decentral storages. The HPs cover the heating demand up to 8 MW, the switch between air-source (ASHP) and ground-source (GSHP) depends on the ambient air temperature as described earlier in Section 6.1.2. The operation of the DHN between May and September is entirely covered by waste heat. Biogas boiler is used to cover the demand when it exceeds 8 MW, the maximum power which could be supplied using the HPs. The injected and extracted power to/from the borehole field follows a reasonable pattern, and respects the maximum limits defined by the non-linear simulation model.

The total annual heat demand of the Wallisellen DHN amounts to 40 GWh/a, consisting of 36.6 GWh/a for space heating and 3.4 GWh/a for domestic hot water. Including DHN losses of 3.9 GWh/a, the total heat demand to be supplied reaches about 44 GWh/a. The largest share of this heat is provided by the heat pumps, which supply 32 GWh/a, corresponding to 73 % of the total demand. This is split almost equally between the air-source heat pump, with 16.7 GWh/a or 38 %, and the ground-source heat pump, with 15.2 GWh/a or 35 %. Waste heat contributes 7.7 GWh/a, or 17.5 %, while the biogas boiler covers the remaining 4.3 GWh/a, corresponding to 9.8 % of the total demand.

Figure 31 shows the hourly heating power delivered by the DHN for the scenario without decentral storages and for three scenarios with decentral storages. The three storage scenarios differ in the assumed heating-peak cost: 5 CHF/kW, 10 CHF/kW, and 100 CHF/kW. This cost represents the weight given to the heating peak in the objective function of the optimization, and thus the importance assigned to peak minimization. The higher the cost, the stronger the incentive to reduce the peak. The optimizer determines the storage volumes by balancing the economic trade-off between the installation cost of the decentral storages and this peak cost: a storage is installed only when its installation cost is lower than the savings achieved through peak reduction. Moreover, as the peak cost increases, each kW of peak reduction becomes more valuable, so it remains economical to install storage up to a larger volume. Hence, larger storage volumes are installed in the scenarios with higher peak costs.

The resulting peak heating powers are summarized in Table 8. Without decentral storages, the peak heating power of the network reaches 19.6 MW. Introducing decentral storages reduces this peak to 14.3 MW at a peak cost of 5 CHF/kW, to 13.2 MW at 10 CHF/kW, and to 12.6 MW at 100 CHF/kW, corresponding to reductions of 27 %, 33 %, and 36 % relative to the case without storage. The corresponding total decentral storage volumes are approximately 547 m³, 798 m³, and 1'548 m³, respectively. This confirms the expected trend: a higher peak cost leads to a larger installed storage volume and therefore to a greater reduction of the network peak.

Furthermore, moving from 5 to 10 CHF/kW increases the total storage volume by about 250 m³ and reduces the peak by 6 percentage points, whereas the much larger step from 10 to 100 CHF/kW reduces the peak further by only about 3 percentage points while installing an additional 750 m³ decentral storage volume. This indicates that the peak reduction begins to approach the limit set by the storage limit constraint and the shape of the load profile.

In addition, the results show a clear diminishing marginal benefit of increasing the storage volume. Increasing the storage volume from 547 m³ to 798 m³, corresponding to equivalent full-load storage durations of approximately 1 h and 1.5 h, respectively, provides a noticeable additional peak reduction. However, the much larger increase to 1'548 m³, corresponding to an equivalent full-load storage duration of about 3 h, only leads to a small further reduction. This suggests that moderate storage volumes already reduce the most critical and easily shiftable peaks, while further peak reduction requires disproportionately larger storage capacities. Very large decentral storage volumes are therefore only justified if the avoided peak capacity has a high project-specific value, for example by avoiding larger generation capacity or network reinforcement.

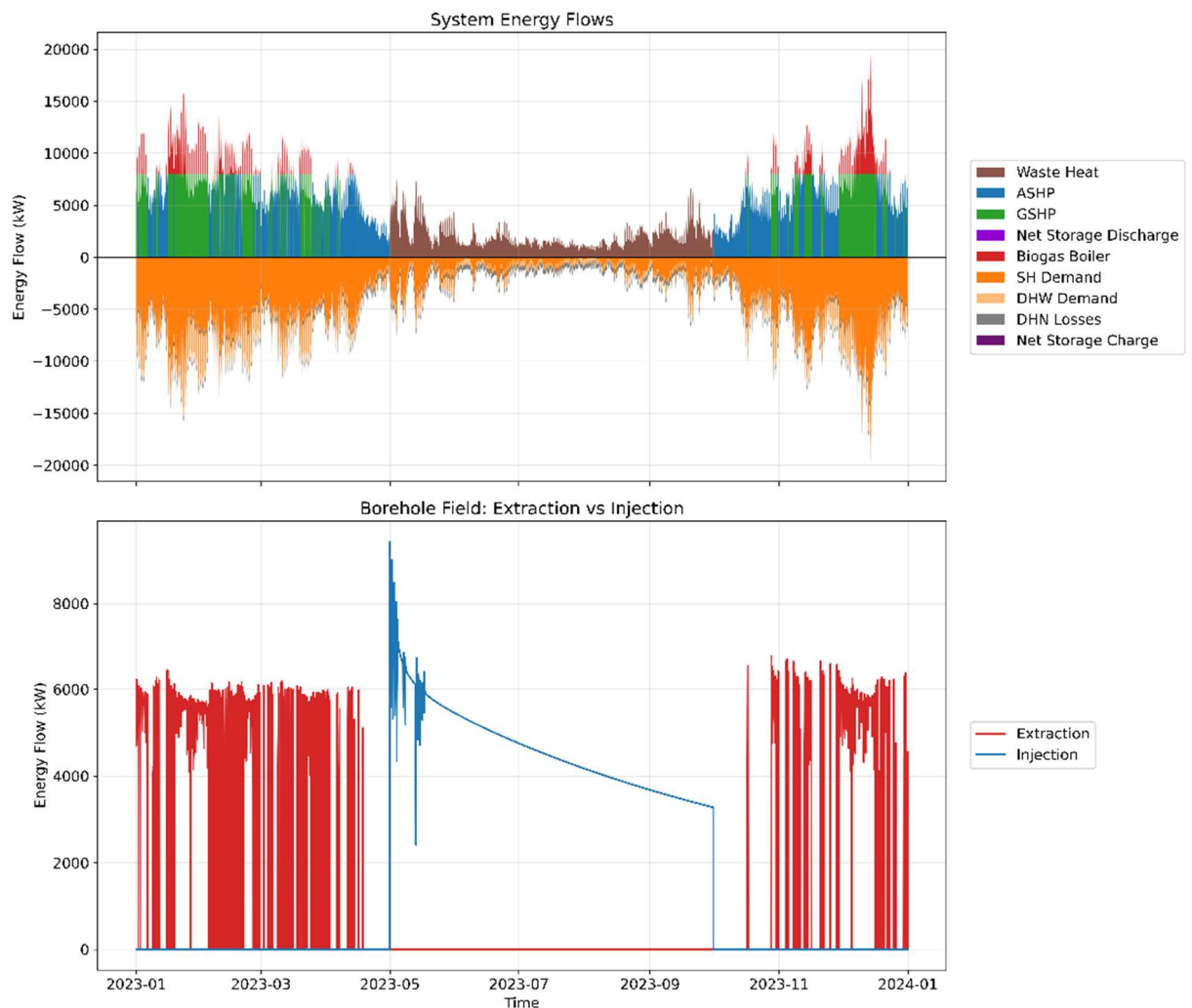


Figure 30: Simulation results for the scenario without decentral storages.

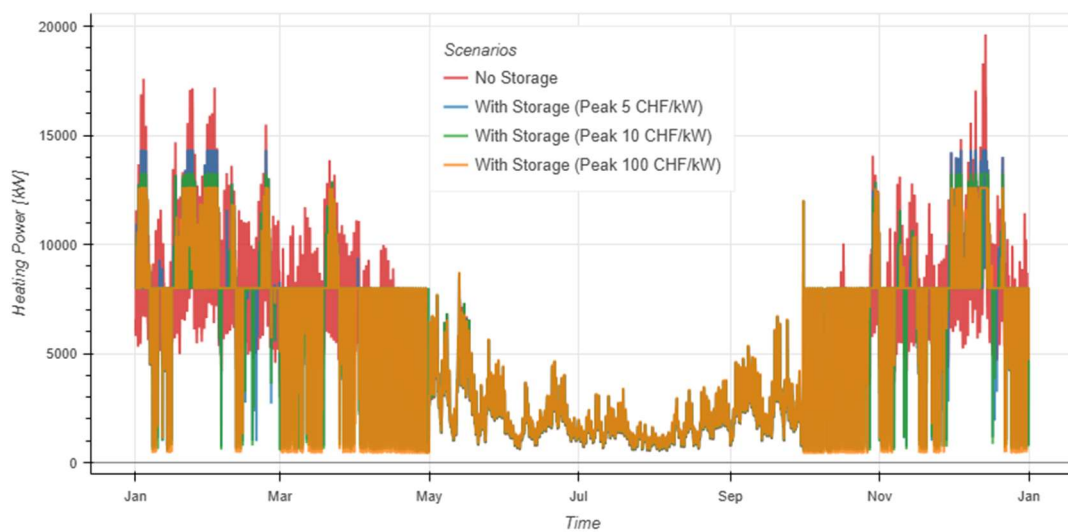


Figure 31: Comparison of simulation results for the scenarios without and with decentral storages. The three scenarios with decentral storages represent the assumed peak power costs of 5 CHF/kW, 10 CHF/kW and 100 CHF/kW.



Table 8: Peak heating power in the DHN without and with decentral storages, for different peak power cost assumptions. Percentage reductions are relative to the no storage case. The table also reports the total decentral storage volumes installed in the building clusters.

Scenario	Peak heating power (MW)	Peak power reduction	Total storage volume (m ³)
No storage	19.6	–	–
With storage (peak cost 5 CHF/kW)	14.3	-27%	547
With storage (peak cost 10 CHF/kW)	13.2	-33%	798
With storage (peak cost 100 CHF/kW)	12.6	-36%	1'548

Figure 32 - Figure 34 show the decentral storage tank volumes that the optimization installs in each cluster for the three peak-cost scenarios (5, 10, and 100 CHF/kW), and Figure 35 summarizes the three cases. The results confirm and refine the trend already seen for the network peak, i.e. a higher peak cost drives the optimizer to install more storage throughout the network.

The largest cluster storage volumes grow from roughly 42 m³ at 5 CHF/kW, to about 58 m³ at 10 CHF/kW, and up to about 122 m³ at 100 CHF/kW, and the same ordering is also visible in the area-normalized storage capacity, expressed per m² of the total building footprint area within a cluster (German: Grundfläche). The area-normalized storage capacity increases from approximately 6 L/m² at 5 CHF/kW peak cost, to about 9 L/m² at 10 CHF/kW, to about 16 L/m² at 100 CHF/kW on average across clusters (Figure 35, right). The specific storage capacity, expressed per kW of cluster peak demand, follows the same pattern: it averages about 30 L/kW at 5 CHF/kW and about 42 L/kW at 10 CHF/kW, while in these two scenarios it stays below the imposed upper limit of 80 L/kW in every cluster. This indicates that for the two lower peak costs the storage sizing is still governed by the economic trade-off rather than by the technical constraint. The 100 CHF/kW scenario behaves differently. Here the specific storage capacity reaches the upper limit of 80 L/kW in every single cluster (Figure 34, top-right), meaning that the technical constraint, rather than the economic balance, determines the installed volume. At this high weighting, the optimizer always installs the maximum amount of storage allowed, so the peak-cost term in the objective function dominates the storage installation cost. This saturation explains the diminishing reduction on the network peak observed earlier between 10 and 100 CHF/kW (where the additional peak reduction was only about 3 percentage points) because the storage volume is already pushed to its allowed maximum and cannot grow further.

The distribution of storage capacity normalized by the ground area of the building (cluster)¹² in L/m² is uneven across clusters. The spread increases with the peak cost: the highest storage intensity rises from about 15 L/m² at 5 CHF/kW to about 22 L/m² at 10 CHF/kW and about 35 L/m² at 100 CHF/kW. Cluster C15 shows the highest storage intensity in all three scenarios, while C2 and C25 also become prominent in the high peak-cost case (100 CHF/kW). Cluster C15 contains only two large non-residential buildings (a swimming pool and a sports hall), which have considerable demand peaks. This explains the high area-normalized storage volume.

¹² Example: for a single-family building with a ground area of 10 m * 10 m, a specific storage capacity of 10 L per m² of ground area of the building gives 1'000 L storage volume, which can usually be integrated well in a cellar of a building of that size.

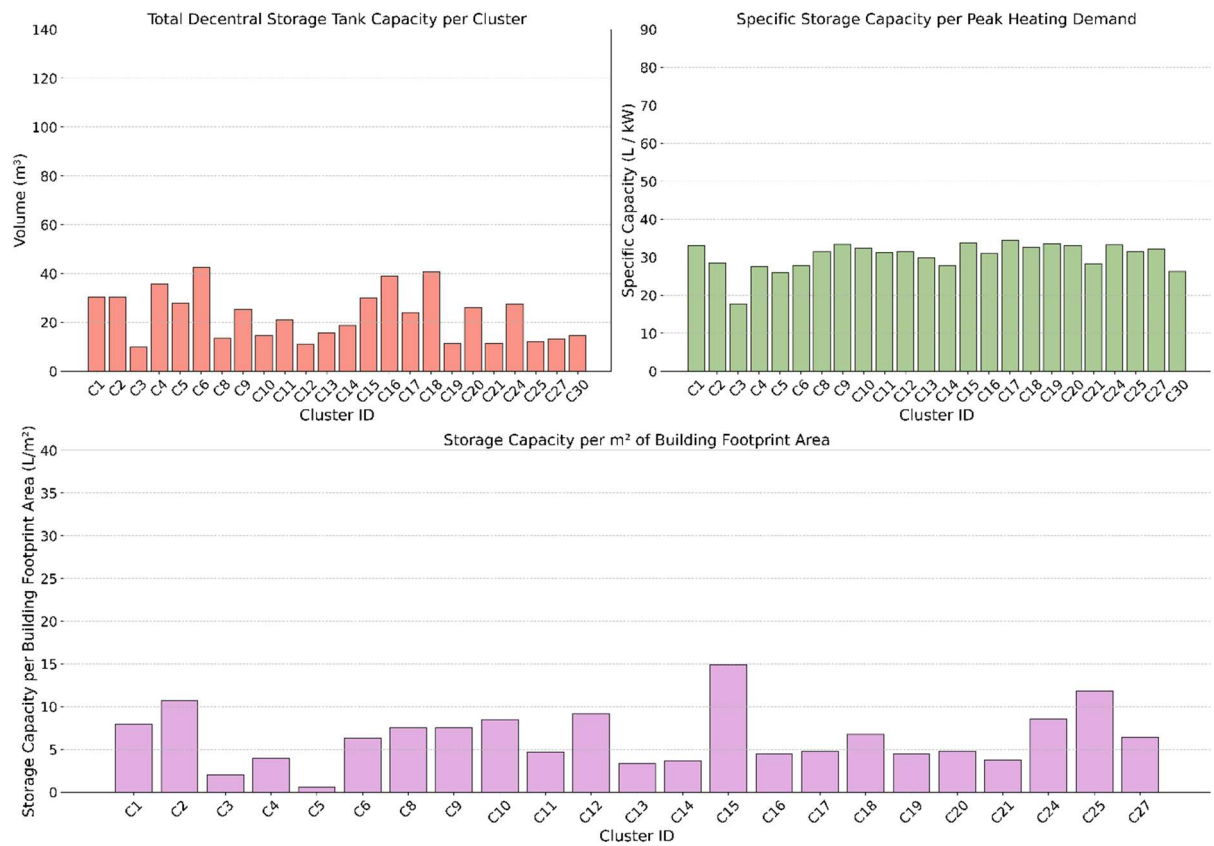


Figure 32: Installed decentral storage capacities for the peak minimization scenarios with peak cost of 5 CHF/kW.

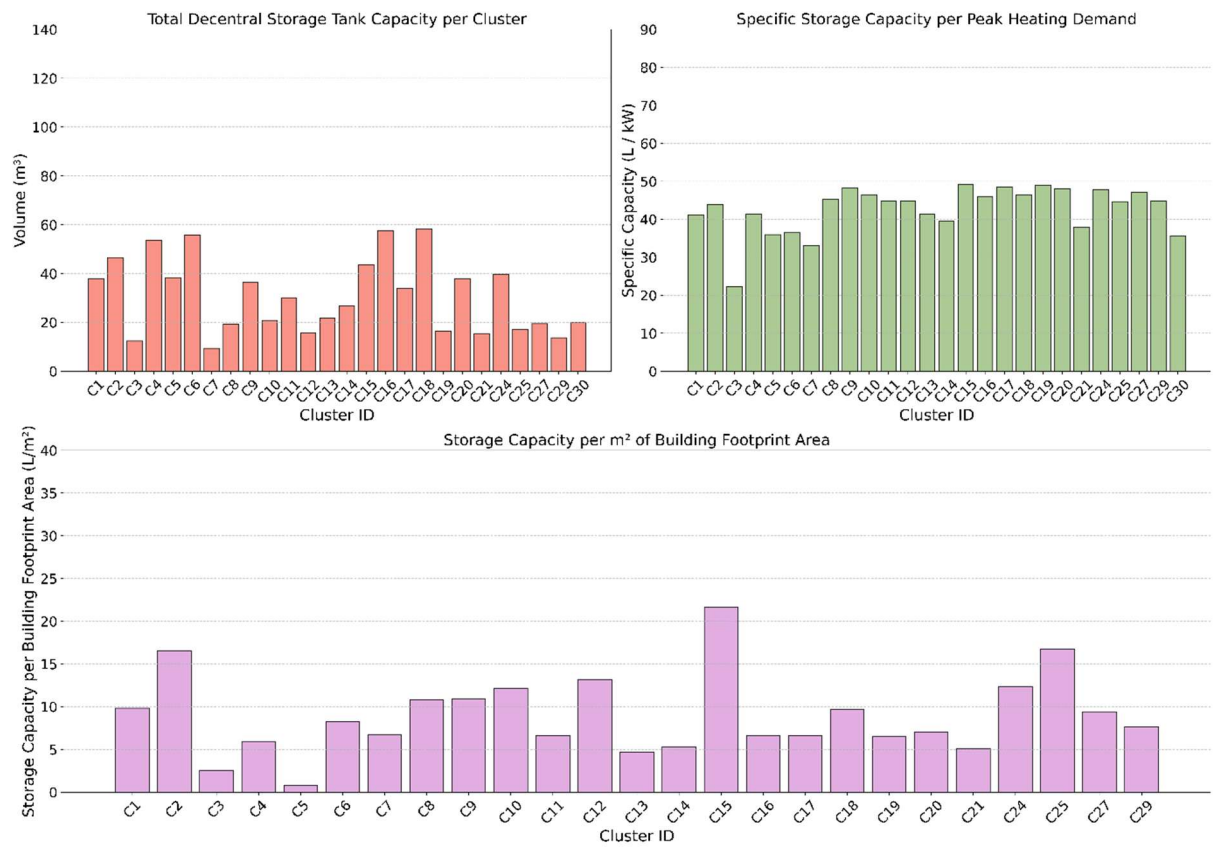


Figure 33: Installed decentral storage capacities for the peak minimization scenarios with peak cost of 10 CHF/kW.

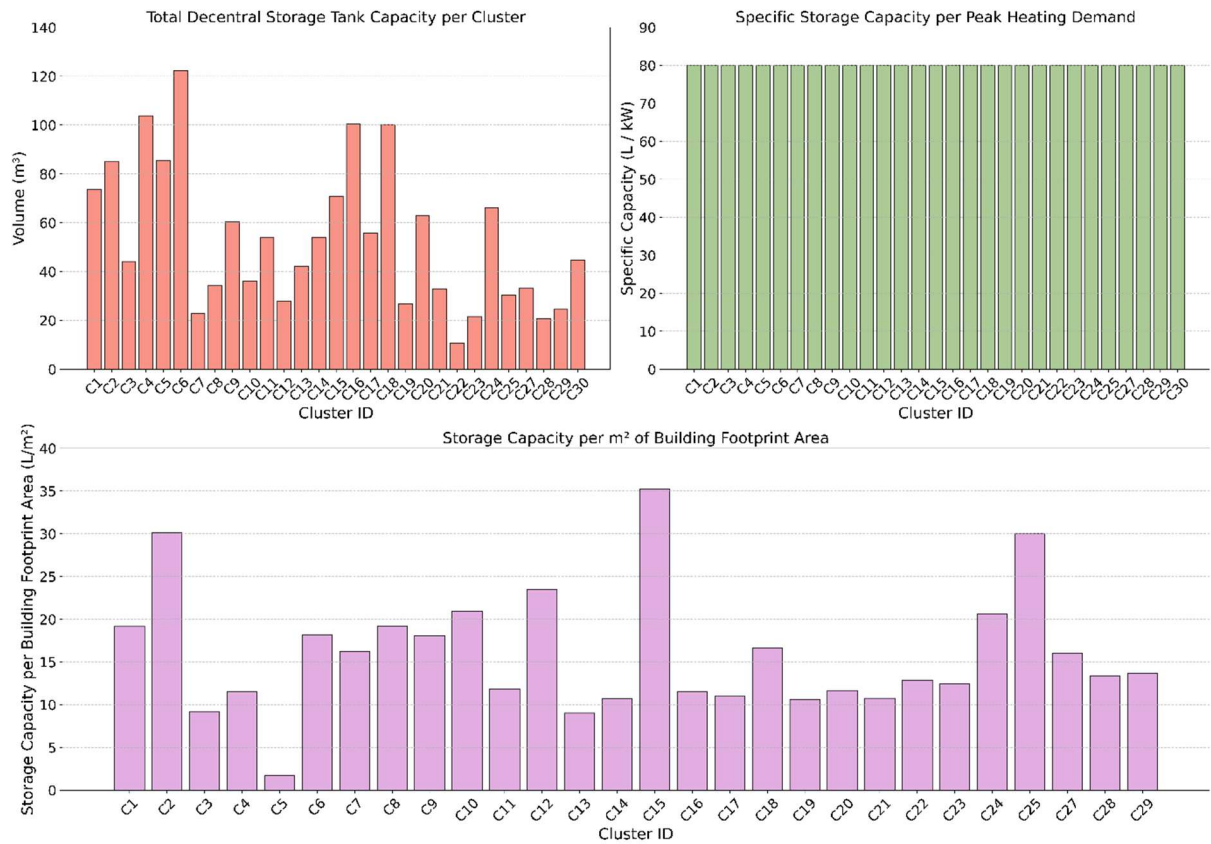


Figure 34: Installed decentral storage capacities for the peak minimization scenarios with peak cost of 100 CHF/kW.

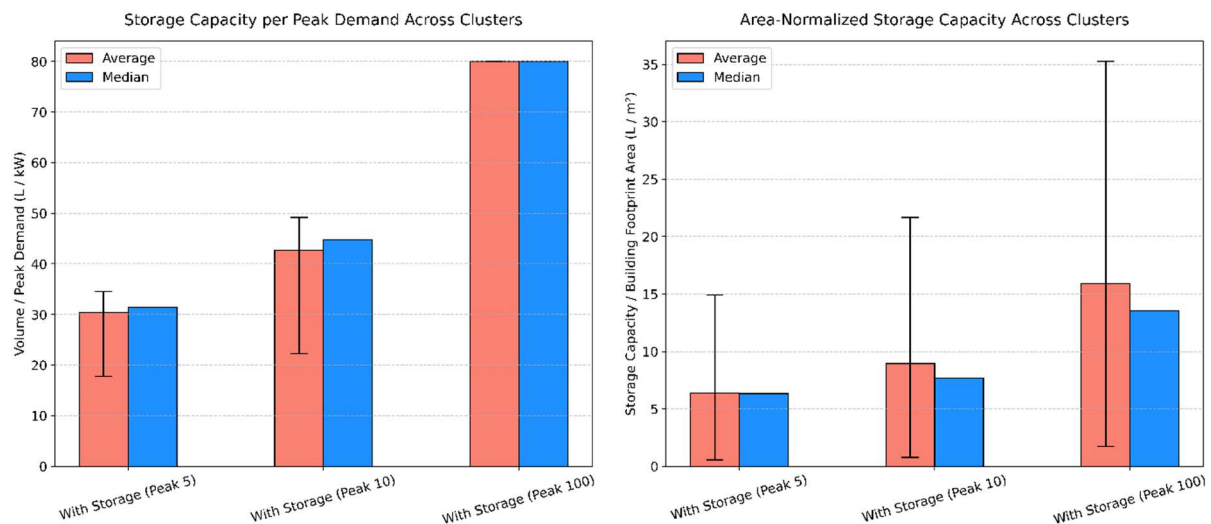


Figure 35: Summary of installed decentral storage capacities for the peak minimization scenarios (peak cost of 5 CHF/kW, 10 CHF/kW and 100 CHF/kW).

The overall effect of the decentral storages on the energy system is summarized in Figure 36. The most pronounced effect is on the biogas boiler, which covers the heating peaks: its annual energy production drops substantially once decentral storages are introduced, by 29.6 % at 5 CHF/kW, 31.1 % at



10 CHF/kW, and 34.3 % at 100 CHF/kW. By shifting demand away from the peak periods, the storages allow a larger share of the heat to be supplied by the heat pumps instead of the biogas peak boiler. As a result, the heat produced by the ground-source heat pump (GSHP) increases by about 8.5 % in all three scenarios, while the output of the air-source heat pump (ASHP) increases by 0.9 %, 1.7 %, and 3.8 % for the increasing peak costs. The increased GSHP operation is also reflected in the borehole-field energy flows, with annual heat extraction increasing by about 9 %.

The larger increase in GSHP production (compared to ASHP) is mainly reflected in the change in full-load operation rather than in total operating hours. For the GSHP, the total operating time remains 2068 hours, however full-load operation increases from 1331 hours without storage to almost the entire operating period with decentral storage. For the ASHP, the operating time remains 3020 hours, while full-load operation increases from 452 to 1498 hours (5 CHF/kW peak cost case), meaning that it operates at full load for about 50% of its operating hours with decentral storage. The stronger increase for GSHP is likely because GSHP operation is more attractive for storage charging due to its higher or more stable COP and therefore lower marginal heat production cost compared to ASHP. Despite the large reduction in biogas consumption, the reduction in annual system cost is comparatively small: 2.9 %, 2.5 %, and 1.2 % for the three scenarios. These costs include the CAPEX of installing the decentral storages based on the cost assumptions reported in Table 3. The operational savings from the lower biogas consumption are limited because the biogas price is very low (0.12 CHF/kWh), so a large reduction in biogas use translates into only minor OPEX savings. Also, since the CAPEX of installing decentral storages grows with the peak cost (as higher storage volumes are installed), the resulting cost reduction becomes smaller as the peak cost increases, even though the biogas reduction becomes larger.

The principal benefit of the decentral storages therefore lies in the reduction of the network peak rather than in a direct reduction of the annual system cost. Due to the reduction of biogas consumption, the operation of the DHN is less affected by potentially increasing cost for biogas in future. The savings could potentially be much higher if biogas prices increase in future (or for example not EU Biogas is used but Swiss Biogas which is currently priced at 20 Rp/kWh).

It should also be noted that the costs shown in Figure 36 do not include the savings in DH pipe cost resulting from the lower network peaks. Without decentral storage, the optimization results indicate that a DN250 main transport pipe is sufficient to meet the network peak demand. With decentral storage, the reduced peak load allows the main pipe to be downsized to DN200. Applying the DH pipe cost assumptions defined in the appendix, this downsizing from DN250 to DN200 due to decentral storages corresponds to savings of about 590 CHF per metre of the main transport DH pipe (or approximately 18 % of the DN250 pipe cost). The smaller pipe diameter also lowers thermal losses (marginally) and a result provides a further, although minor, operational benefit over the lifetime of the DHN. However, retaining larger pipe diameters may still be advantageous if future network extensions or the connection of additional customers are planned.

Furthermore, the peak cost assumptions should be interpreted as sensitivity parameters or weights that represent the assumed benefit of reducing the maximum thermal peak load. They indicate how much the optimization is allowed to incentivize each kW of avoided peak capacity and therefore determine how much decentral storage is economically justified. Notably, even when no peak cost is applied, the cost optimization installs decentralized storage because it enables greater use of the lower-cost heat pumps and reduces biogas consumption. Additional peak reduction is achieved only when this benefit is explicitly represented in the objective function. The lower peak-cost values, 5-10 CHF/kW, represent cases where peak reduction has only a limited economic value, for example through reduced peak operation-related costs. The 100 CHF/kW case should be interpreted as a high-value peak reduction case, where reducing the peak may also help avoid capacity related investments, such as larger peak generators, pipe reinforcement, or additional installations. The results can therefore be used by planners by comparing the project-specific benefit of avoided peak capacity with the storage volumes and peak reductions obtained in each scenario. If the avoided peak capacity has little economic value, only small decentral storage volumes may be justified. If peak reduction can avoid costly infrastructure or peak capacity investments, larger decentral storage volumes may become reasonable.

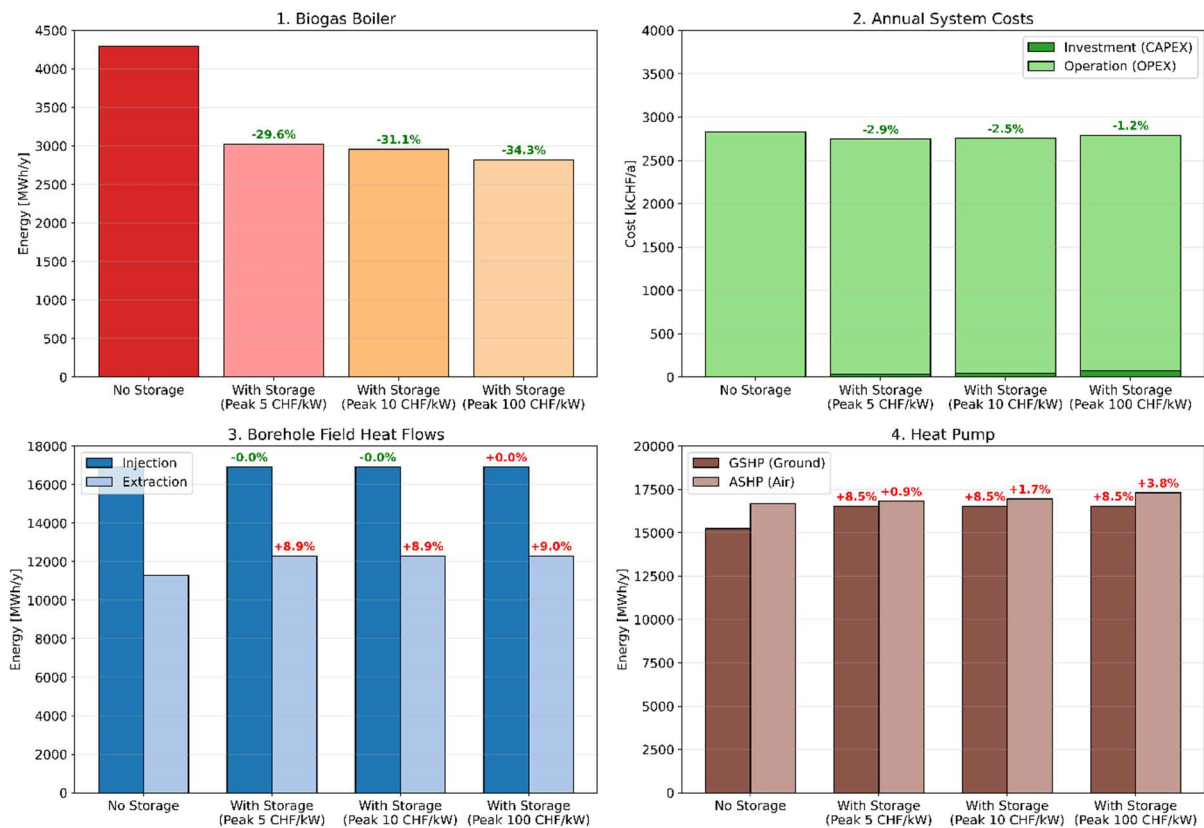


Figure 36: Comparison between biogas consumption, system costs, injection/extraction from borehole field and total heat produced by HPs for the four considered scenarios.

Figure 37 shows the relation between annual system cost and annual emissions for the no-storage reference and the decentral-storage cases with increasing peak-cost penalties. The no-storage reference has both the highest cost and the highest emissions. Even without a peak-cost penalty, the introduction of decentralized storage reduces annual emissions by 7.9 % compared with the no-storage case, primarily because it allows more heat to be supplied by the heat pumps and reduces the use of the biogas boiler, as shown in Figure 36. With increasing peak-cost penalties, the annual emissions reduce further, by 8.1 % at 5 CHF/kW, 8.4 % at 10 CHF/kW, and 8.8 % at 100 CHF/kW. However, these additional emission reductions are achieved at relatively higher annual system cost. The figure therefore illustrates the trade-off between stronger peak-reduction incentives and the associated environmental benefit.

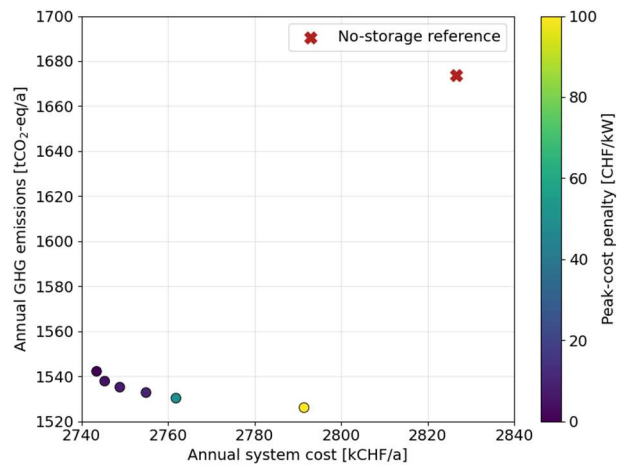


Figure 37: Trade-off between annual system cost and annual emissions for the no-storage reference and the decentral-storage scenarios. The red cross denotes the no-storage reference case, while the circles from left to right represent increasing peak-cost penalties of 0, 5, 7.5, 10, 50, and 100 CHF/kW.

The Wallisellen case study focused on the peak-reduction potential of newly installed decentral storages in the aggregated network model. Several additional aspects were not included in the present analysis but could be relevant for a more detailed planning assessment. First, already existing storage capacities in the Wallisellen network could be integrated once their size and location are known. This would allow the additional benefit of new decentral storages to be assessed more realistically. Second, separate storage concepts for space heating and domestic hot water could be modelled in order to quantify the individual contribution of each demand component to peak-load reduction. Third, the interaction between central and decentral storage could be investigated by varying the size of a central storage tank and analysing its influence on the required decentral storage volume and on peak boiler operation. Finally, the sensitivity of the results to biogas and electricity prices could be analysed, since changes in these energy prices may influence the economic value, operation and optimal sizing of decentral storages.

6.2 Case Study 2

The case study 2 examines an existing district heating network (DHN) in Switzerland. The network is still under development, with construction and operation having started in year 2023. Similar to the first case study, optihood was used to assess the potential of decentralized storages to minimize the thermal power peaks in the network.

6.2.1. Description of the case study

The DHN is supplied from a central energy centre (EZ). The primary heat source is the waste heat from the process cooling of a food-production facility, which uses water from a nearby lake as its cooling source and generates waste heat throughout the year. This waste heat serves as the source for heat pumps in the energy centre. In addition to the heat pumps, the energy centre contains a pellet boiler and a gas boiler to cover demand peaks, and two storage tanks that provide a thermal buffer between the heat pumps and the network's demand. The main components of the energy centre are listed in Table 9.



Table 9: Energy system components in the DHN investigated in case study 2.

Component	Capacity	Description
Heat pumps (2 units)	2 × 1600 kW	Modulating
Pellet Boiler	1200 kW	Efficiency 81%
Gas Boiler	500 kW	Efficiency 83.8%
Central Storage Tanks (2 units)	2 × 64 m ³	Thermal buffer between heat pumps (HPs) and demand (state of charge set point: 50 %)

The DHN (Figure 38) connects 55 buildings (the energy centre and 54 consumers), through a total of 112 pipes. The pipe diameters (DN) were taken from the data provided by the industry partner, and the pipe lengths were approximated from maps. The network was analysed with a dynamic simulation over a heating period in optihood. Beyond quantifying the peak-shaving potential of the decentral storages, the simulation was used to assess how heavily each network strand is utilised and how much reserve capacity it still available for a future expansion, and to determine the storage volume and location that would be required to minimise the peaks currently covered by the pellet and gas boilers. In addition to the current network, a future expansion scenario up to 2030 was analysed, in which 29 additional buildings are connected to the network.

The heat demand profiles are based on real measurement data from 2025. Five buildings had no demand data, and 23 buildings had no data before May/June 2025; the remaining data was complete, with no missing values or obvious outliers. To deal with these gaps, the simulation period was limited to October-December 2025. For the five buildings without measurement data, demand profiles were generated with the nPro tool. Figure 39 and Figure 40 show the hourly, monthly total and monthly peak heat demand of the investigated DHN. The heating demand of the DHN varies from 335 kW to 2000 kW. For the expansion to 2030 scenario, 29 additional buildings were clustered to 4 representative buildings placed at approximate locations, giving a modelled network of 59 buildings (EZ + 54 + 4). A residential demand profile was assumed for these 4 buildings and scaled to match their peak power, the connecting pipe lengths were assumed to be zero (so pipe losses were not modelled), and no decentral storages were modelled in the future buildings.

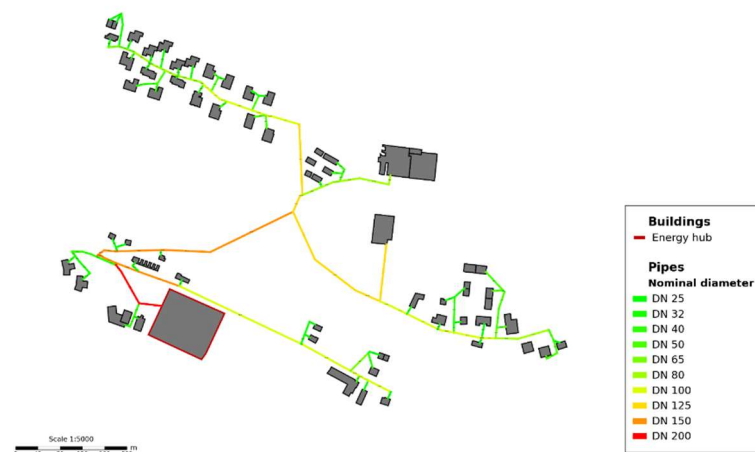


Figure 38: DHN modelled in optihood for the case study 2. The buildings are represented by grey rectangles: the one with red outline represents the energy centre (EZ), others with black outlines are individual consumers.

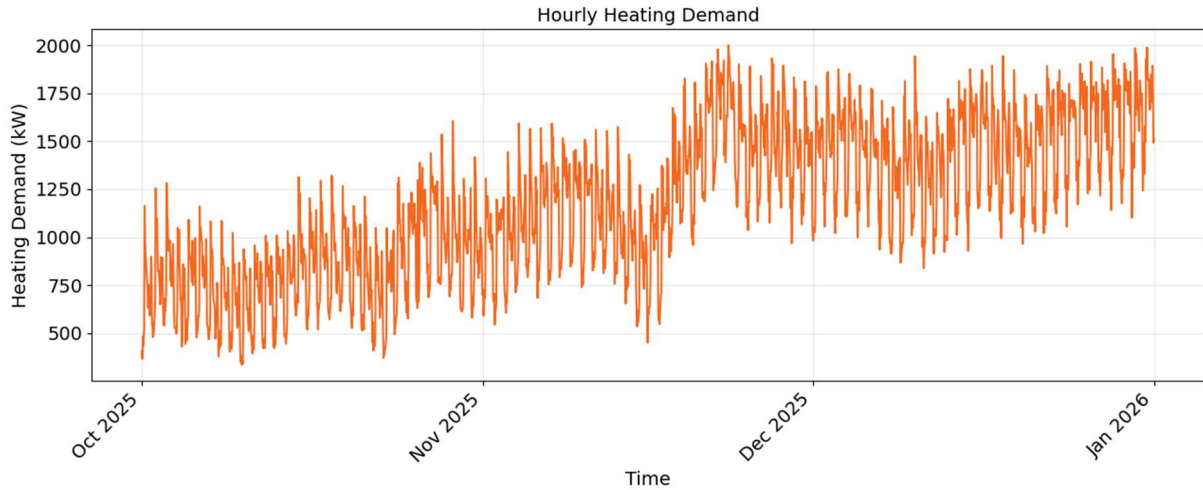


Figure 39: Hourly heating demand of the investigated DHN from the real measurement data of 2025 for 50 buildings and generated profiles of 5 buildings (missing data).

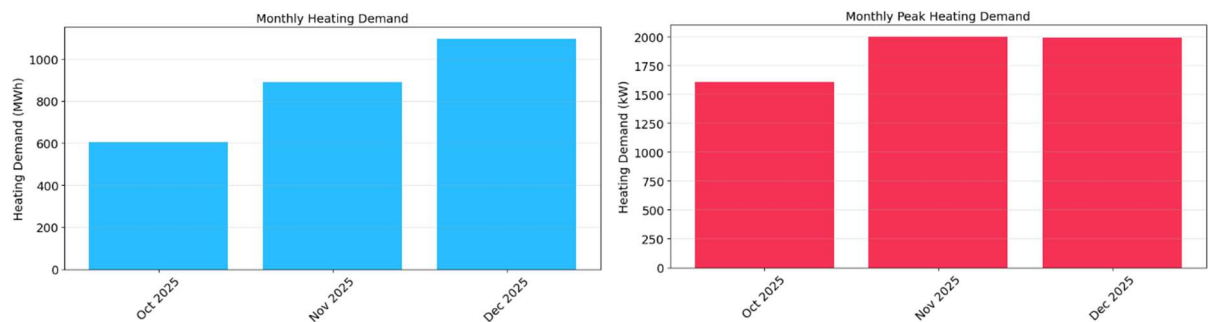


Figure 40: Monthly total and peak heating demand of the investigated DHN from the real measurement data of 2025 for 50 buildings and generated profiles of 5 buildings (missing data).

6.2.2. Energy system modelling and assumptions

This subsection describes how the energy system was represented in optihood.

The two heat pumps were modelled as a single heat pump with a combined capacity of 3200 kW and a modulation range of 10-100 %. In real operation, one heat pump runs first and modulates down to 20 % of its own capacity, which corresponds to 10 % of the combined capacity; the second heat pump is only started when the required power exceeds the capacity that the first operating heat pump can deliver. The COP of the heat pump depends on the temperature of the waste heat delivered on the evaporator-side. This temperature profile is obtained from the measurement data (average of the evaporator inlet and outlet temperatures). Start-up costs were added to the heat pump to prevent it from short-cycling (switching on and off repeatedly).

The central buffer storage was modelled as a single 128 m³ tank, combining the two 64 m³ tanks. It is considered fully charged at 75 °C and empty at 50 °C, the latter corresponding to the average return temperature of the network. The initial storage level was set to 50 % and balanced to the same level at the end of the simulation, with a minimum allowed level of 40 %.



The dispatch of the units follows a fixed order: heat pump first, then pellet boiler, and lastly gas boiler. This order is not imposed manually but results automatically from the differences in the energy prices used in the model (Table 10).

Table 10: Price and availability assumptions made for the modelled energy sources.

Source	Price	Availability Restrictions
Waste heat	0 (free)	Available year-round
Wood pellets	10.6 Rp/kWh	-
Natural gas	16.5 Rp/kWh	-
Electricity	27 Rp/kWh	-

6.2.3. Results

The network was evaluated in three configurations namely, (i) without decentral storages, (ii) with a uniform 2 m³ storage per building, and (iii) with a flexible 2-5 m³ storage per building, for both the current network and the planned 2030 expansion. The peak heating power and annualized cost for all cases are summarised in Table 11.

Current network (54 consumers).

When decentral storages are introduced, the peak heating power supplied by the energy centre falls from 2096 kW to 1777 kW with 2 m³ storages (-15.2 %) and to 1746 kW with 2-5 m³ storages (-16.7 %) as shown in Figure 41. The storages achieve this by charging during off-peak periods and discharging during the demand peaks, which partly decouples the building peaks from the energy centre. As a result, the load on the main transport pipe (heat flow from the energy centre) is reduced, while the smaller pipes connecting the individual buildings carry the additional storage charging flows and are utilised more intensively, with several connecting pipes reaching close to their capacity limits. As a result, these connecting pipes effectively become the limiting factor. Although the larger storages provide more energy capacity, this additional flexibility cannot be fully exploited because the charging and discharging flows are constrained by the capacity of the building connection pipes. Moreover, the 2-5 m³ case does not correspond to all buildings having 5 m³ tanks: 22 out of 54 buildings remain at the minimum volume of 2 m³, only 6 buildings reach 5 m³, whereas the average installed storage size is about 2.84 m³. As a result, the additional peak reduction in the energy centre obtained by increasing the storage from 2 m³ to 2-5 m³ is small (from -15.2 % to -16.7 %).

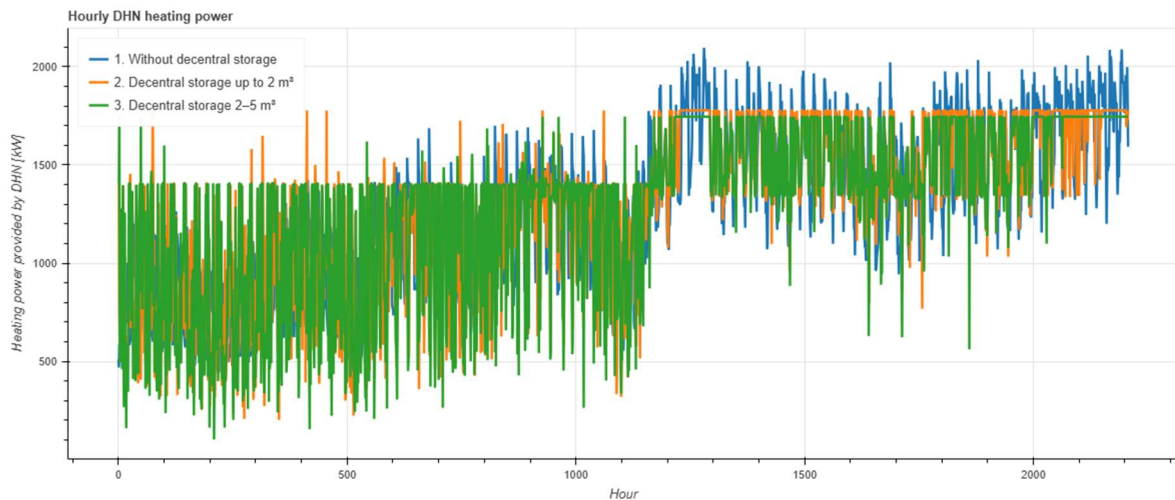


Figure 41: Peak heating power of the existing DHN in case study 2 without and with decentral storages.

The annualized cost increases with the installation of the decentral storages, by 3 % for the 2 m³ case and 8 % for the 2-5 m³ case (Figure 42). As in the first case study, this cost figure includes the investment in the decentral storages but does not account for the reduced peak electricity consumption nor any savings on the network pipes that the lower peak could allow in case new pipes would be installed in the investigated DHN in future. However, since the peak heat demand supplied by the network is covered predominantly by the heat pumps (HPs), a reduction in peak heating power of about 15-17% is expected to translate into a reduction of the same order of magnitude in the peak electricity consumption of the HPs.

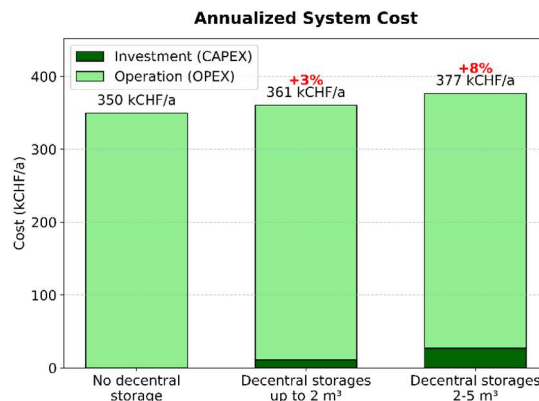


Figure 42: Annualized total cost, including investment cost due to decentral storages and operation cost from the use of energy resources.

Future expansion scenario (up to 2030).

Connecting the additional buildings increases the peak load on the network by 62 % (from 2096 kW to 3400 kW). With decentral storages, the peak heating power falls from 3400 kW to 2660 kW with 2 m³ storages (-22 %) and to 2450 kW with 2-5 m³ storages (-28 %), as shown in Figure 43, a larger relative reduction than in the current network, as the expanded network has a higher peak to shave. The optimizer installs 5 m³ storages in most buildings, and the connecting pipes are utilised much more heavily than in the current network scenario. The peak reduction could potentially be higher if the connecting pipes offered more capacity.

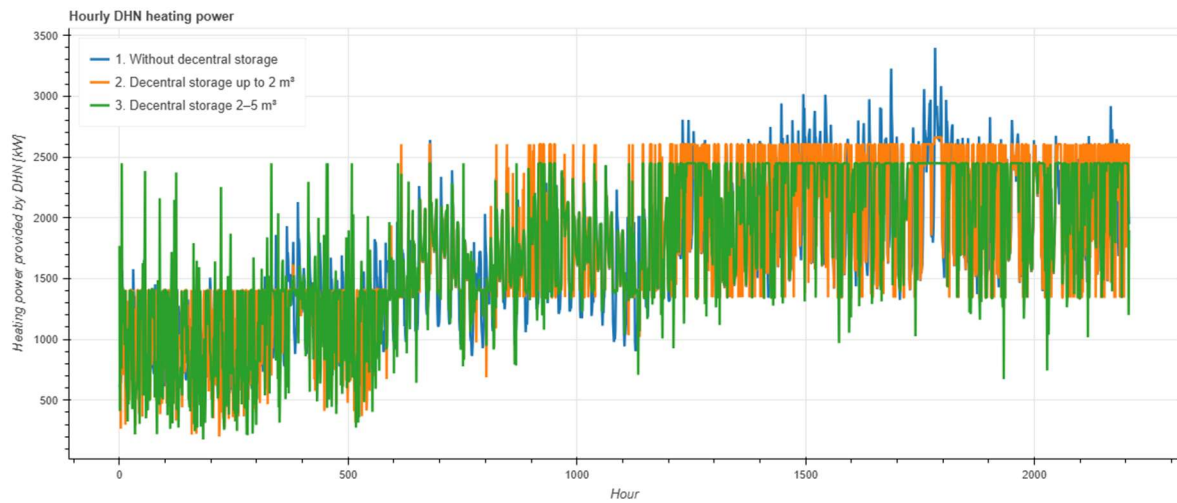


Figure 43: Peak heating power of the DHN in future expansion scenario (case study 2) without and with decentral storages.

The annualized cost again increases with the storages, by 2 % for the 2 m³ case and 7 % for the 2-5 m³ case (Figure 44).

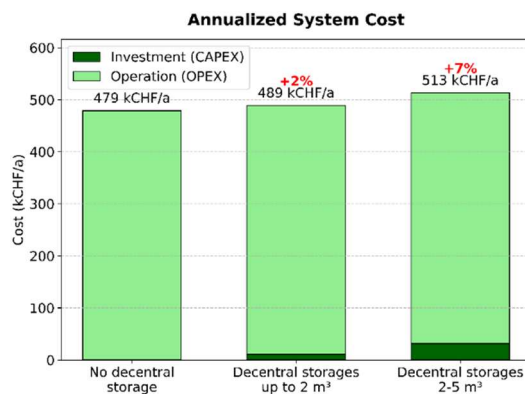


Figure 44: Annualized total cost, including investment cost due to decentral storages and operation cost from the use of energy resources.

Table 11: Peak heating power and annualized cost for the DHN in case study 2 (existing and expansion cases). Peak reduction percentages and cost percentages in brackets are relative to the corresponding no-storage case.

Network	Scenario	Peak heating power (kW)	Annualized cost (kCHF/a)
Current	No storage	2'096	350
Current	Decentral storage 2 m ³	1'777 (-15.2 %)	361 (+3.1 %)
Current	Decentral storage 2-5 m ³	1'746 (-16.7 %)	377 (+7.7 %)
Expansion	No storage	3'398	479
Expansion	Decentral storage 2 m ³	2'660 (-21.7 %)	489 (+2.1 %)
Expansion	Decentral storage 2-5 m ³	2'448 (-28.0 %)	513 (+7.2 %)



7 Conclusions

This project investigated how decentralized thermal energy storage units can support the design and operation of district heating networks (DHNs). The focus was on reducing network peaks, reducing bottlenecks/overloads in network sections, estimating suitable storage sizes, and providing a practical tool for planners. The analysis combined dynamic optimization with optihood, a practical planner workflow based on PeakAnalyser and THENA, and two real case studies.

Impact on cost and peak load

The results show that decentralized thermal storages are useful when the problem is a short peak in heat demand. They can reduce the maximum power that must be supplied by the energy centre, and they can reduce the heat flow through specific network sections during peak periods.

In the idealized biomass network investigated (with 0.93 GWh/a heat demand), the cost-optimal total storage volume was approximately 18 m³ in all three investigated storage configurations: a fully central storage solution, a mixed central and decentralized solution in which the central storage volume corresponds to the legally required minimum buffer storage for the biomass boiler, and a fully decentralized solution. Therefore, if the network has no local pipe overload, decentralized storage does not necessarily reduce the total storage volume or the levelized heat cost. In that case, the main difference is the location of the storage. This is still relevant in practice, because decentralized storage can provide additional flexibility when space for storage at the heating centre is limited. However, for biomass boilers, the legally required minimum buffer storage dedicated to the boiler operation must still be installed centrally and cannot be replaced by decentralized storages in the network. Decentralized storage should therefore be understood as a complement to the required central boiler storage, for example for peak load management.

The advantage of decentralized storage becomes clearer when a network section has insufficient capacity to meet the required peak load. In the investigated biomass network, an increased demand at one customer connection was used to represent the connection of additional buildings. For this case, installing decentralized storage close to the additional demand was cheaper than replacing the affected network sections with larger pipes. The storage allowed more heat to be delivered through the existing pipes over a limited period by charging before the peak and discharging during the peak. However, this effect is limited by the pipe capacity. When the demand increase became too large, decentralized storage alone was not sufficient, and the affected pipes still had to be replaced to increase their capacity.

Furthermore, the peak reduction from the use of decentral storages can be substantial. In the idealized biomass network, decentralized storage reduced the maximum heat production peak from 464 kW to 318 kW, corresponding to a reduction of 31 %. Smaller storages also had a clear effect: 0.5 m³ per building reduced the peak by about 13 %, 1 m³ by about 20 %, 1.5 m³ by about 23 %, and 2 m³ by about 25 %. The additional system cost increase for the investigated peak-shaving cases was small compared with the achieved peak reduction.

The Wallisellen case study also showed a strong peak reduction. Without decentralized storage, the peak heating power was 19.6 MW. With decentralized storage, the peak was reduced to 14.3 MW, 13.2 MW, and 12.6 MW, depending on the assumed economic value of a peak reduction. This corresponds to power reductions of 27 %, 33 %, and 36 %. This result shows that decentralized storage can reduce the required peak capacity at the energy centre, especially when a peak boiler or another costly peak unit would otherwise be needed. Alternatively, the main transport pipe of the DHN could be sized smaller, which would result in significant cost savings.

In the case study 2, the peak reduction was smaller but still relevant. In the current network, 2 m³ storages reduced the peak heating power by 15.2 %, while 2-5 m³ storages reduced it by 16.7 %. In the expansion scenario with further customers connected, the same storage options reduced the peak by 21.7 % and 28.0 %, respectively. The annualized cost increased because of the investment cost of the



storage tanks. In the case study 2, the cost increase was 3.1 % to 7.7 % in the current network and 2.1 % to 7.2 % in the expansion case. This means that decentralized storages are economically beneficial only if the reduced peak has a clear value, for example by avoiding a larger heat pump, reducing peak electricity consumption cost for operating heat pumps, reducing peak boiler operation or avoiding pipe replacement. None of these potential effects were considered in this economical assessment.

Sizing of decentral storages from investigated DHNs

The optimal storage size depends strongly on the purpose of the storage. If the aim is only to distribute the cost-optimal storage volume in the biomass network investigated (with 0.93 GWh/a heat demand), relatively small decentralized tanks are sufficient. In the mixed central/decentralized case, the optimized solution used 8.7 m³ of central storage and approximately 9.5 m³ of total decentralized storage volume, corresponding to around 800-1000 L per building. In the fully decentralized case, the total storage volume was again about 18.2 m³, with nearly 2 m³ per building.

If the aim is stronger peak shaving, larger tanks are needed. In the idealized biomass network, the highest peak reduction was achieved with larger decentralized storages: approximately 3.5-4 m³ in residential buildings, 6.5 m³ in the production building, and 11 m³ in the school. These volumes show the order of magnitude required when the goal is to strongly reduce heat production peaks.

The Wallisellen case study gives additional sizing indicators for larger DHNs. In this case, the decentralized storages were modelled at building-cluster level. The largest optimized cluster storage volumes were about 42 m³, 58 m³, and 122 m³ for the three peak-cost assumptions. The storage volume per building footprint area is a useful planning indicator for this case, because it gives an impression of how much storage volume would have to be integrated in or near the buildings. The average values were about 6 L/m², 9 L/m², and 16 L/m² of building footprint area. The specific storage volume per peak demand was about 30 L/kW for the lower peak-cost case and about 42 L/kW for the medium peak-cost case.

In the case study 2, a simple 2 m³ storage per building already achieved most of the peak reduction in the current network. Increasing the allowed storage size to 2-5 m³ gave only a small additional peak reduction in the current network, because the connecting pipes to the individual buildings became the limiting factor for charging and discharging. In the expansion scenario, the larger 2-5 m³ storages had a stronger effect. This shows that storage size must be checked together with the pipe capacity at the storage location.

Overall, decentralized storage should be dimensioned from the energy contained in the peak that should be reduced. The relevant value is not only the maximum power in kW, but the energy above the selected power limit in kWh. The available temperature difference between charged and discharged storage states then determines the required storage volume.

Operating strategy for peak shaving

The basic operating principle for peak shaving is straightforward. A part of the energy needed during an upcoming peak is stored in advance in the decentralized storage. During the peak, the storage discharges locally. This reduces the heat that must be produced by the energy centre or transported through the hydraulically constrained network section during the peak hour.

In the dynamic optimization, this operation is determined by the optimizer with full knowledge of the future heat demand. The optimizer therefore decides when to charge and discharge each storage so that the selected objective, for example minimizing the peak power supplied by the heat producer, is achieved as effectively as possible. This represents an ideal operation and gives an estimate of the technical peak-shaving potential of decentralized storages.

In practical applications, this ideal operation has to be approximated by a control strategy. A simple rule-based control could follow four steps. First, a power limit is selected. This can be the maximum desired



output of the heat producer, the capacity of a network section, or the power level above which a peak boiler would start. Second, the expected demand profile (synthetic or derived from measurement data) is checked to identify periods where the demand is expected to exceed this limit. Third, the energy above the limit is calculated. This is the energy that must be shifted into the storage before the peak. Fourth, the storage is charged before the peak during hours when spare heat production or pipe capacity is available and discharged during the peak.

Such a rule-based strategy is especially suitable for short and recurring demand peaks, such as typical morning peaks during the heating season. In such cases, the decentralized storage can be charged whenever sufficient spare heat production and pipe capacity is available, for example when the ambient temperature falls below a defined threshold. However, rule-based control has clear limitations. It may not charge the storage at the best time, may not choose the optimal state of charge before each peak, and may not coordinate several decentralized storages in the most effective way.

A more advanced approach would be model predictive control (MPC). Currently, rule-based control is typically the simpler and more common approach in practice. Implementation of MPC is more demanding as it requires additional infrastructure, such as reliable measurements of storage state of charge and network operation, communication links to decentral storage units, controllable valves or charging stations, integration with the heat producer and SCADA/control system. MPC could use forecasts of heat demand, weather conditions, storage state of charge, and available generation or pipe capacity to optimize the storage operation over a rolling time horizon. This would allow the real operation to come closer to the optimized operation used in the simulations. Nevertheless, even MPC would not fully reach the ideal optimization results, because forecasts of weather and heat demand will always deviate from reality and because the implemented controller will have a limited prediction horizon and simplified system representation. The optimization results should therefore be interpreted as an upper-bound potential, while practical control strategies determine how much of this potential can actually be achieved.

Furthermore, there are physical constraints that apply to any operating strategy. Decentral storage is less suitable for long periods of high demand, if the storage capacity is not sufficient to cover the entire period. It also requires enough free heat production and pipe capacity before the peak to charge the storage. If the pipe to the building is already close to its limit before the peak, a larger storage tank alone will not solve the problem.

Planner toolchain: PeakAnalyser and THENA

The project provides a simple workflow for planners by combining PeakAnalyser and THENA.

PeakAnalyser is used first. The planner loads a measured or synthetic demand profile for a building, a customer connection, or a network branch. A power limit is then selected, for example the capacity of a critical network section. PeakAnalyser identifies the periods where the demand is above this limit and calculates the energy that must be shifted into storage. The result is given in kWh and represents the minimum useful storage capacity for the selected peak.

This energy and peak capacity values are then entered in THENA, where the whole network has been prepared for analysing. Together with the network flow and return temperatures, THENA calculates the required storage volume in m³. THENA can also be used to check how the storage affects pipe sizing, pipe costs, and network losses. The planner can therefore in short time test different storage sizes, storage locations, and pipe capacity limits without carrying out a full dynamic optimization.

The workflow is useful for early planning and for checking expansion options in existing networks. It does not replace a detailed dynamic simulation when the full system operation must be optimized. However, it gives planners a practical workflow to estimate whether decentralized storage can reduce a specific heat production peak or relieve a specific network section.



Overall conclusion

Decentralized thermal storage is most useful for short and known peak loads. It can reduce the maximum heat production power, reduce the operation of peak units, and temporarily relieve network sections that are overloaded during peak periods. It is also useful when there is not enough space for additional central storage at the heating centre.

Decentralized storage is not a complete substitute for larger pipes or larger heat generators. If a branch has a permanently higher heat demand, or if the peak lasts too long, the affected pipes or heat production units may still have to be enlarged. The benefit of decentralized storage therefore depends strongly on the shape of the demand profile, the duration of the peak and the available pipe capacity before the peak.

Across the investigated cases, decentralized thermal storages reduced thermal peak loads by approximately 13-36 %, depending on the network, storage size, and optimization objective. In the idealized biomass network, storages of 0.5-2 m³ per building reduced the peak by 13-25 %, while larger storages achieved a maximum reduction of 31 %. In Wallisellen, the optimized cluster storages reduced the network peak by 27-36 %, with total decentralized storage volumes between 547 m³ and 1'548 m³. This corresponds to approximately 12-35 m³ of storage per GWh/a of supplied heat demand, or about 100 - 220 m³ per MW of reduced peak capacity. In the case study 2, the peak reduction was smaller but still relevant, ranging from 15-28 % depending on the network expansion scenario and storage sizing. These results show that moderate storage volumes can already reduce the most pronounced peaks, while additional peak reduction often requires disproportionately larger storage capacities.

For planning, decentralized storage should be compared directly with the alternatives: central storage, larger pipes, larger heat production units, demand-side measures or increasing the supply temperature up to the design-limit. The best solution is case-specific. The results of this project show that decentralized storage can be a cost-effective solution when the problem is a short peak or a local pipe bottleneck/overload, especially if it can avoid pipe replacement, larger peak generation units, or other capacity-related investments. But its value must be checked using the actual demand profile and the actual network constraints. If the network already has sufficient reserve capacity, for example for future expansion, decentralized storage may not directly pay off. In such cases, the additional storage investment can increase the annualized system cost, as shown in the case study 2, where the cost increase reached up to about 8 %. However, future electricity prices with variable tariff structures may offer additional benefits, especially in heat-pump-based networks.

Finally, the results presented in this report should be interpreted in the context of the investigated case studies and modelling assumptions. The peak-reduction values represent estimates of the technical potential of decentral thermal storages under optimized operation, where storage charging and discharging is controlled with full knowledge of the future heat demand. In practice, real control strategies will not be able to exploit this potential fully. Similarly, the storage sizes and peak reductions reported here should be understood as case study specific results rather than universal design rules. Their transferability depends on the demand profile, network topology, available pipe capacity, heat-generation system, storage constraints, and the economic value assigned to peak-load reduction.



8 References

- Bundesamt für Energie. (2021). *Systemkennwerte Graue Energie Gebäudetechnik* [Schlussbericht].
- Bundesamt für Energie BFE. (2024). *Schweizerische Gesamtenergiestatistik 2023*. <https://www.bfe.admin.ch/bfe/de/home/versorgung/statistik-und-geodaten/energiestatistiken/gesamtenergiestatistik.html/>
- Dimri, N., Zenhäusern, D., Carbonell, D., Jobard, X., Jacquot, V., François, A., Capezzali, M., & Fesefeld, M. (2023). Optihood – a multi-objective analysis and optimization framework for building energy systems at neighborhood scale. *Journal of Physics: Conference Series*, 2600(8), 082027. <https://doi.org/10.1088/1742-6596/2600/8/082027>
- Haller, M., & Ruesch, F. (2019). *Fokusstudie «Saisonale Wärmespeicher – Stand der Technik und Ausblick»*. Auftraggeber: Forum Energiespeicher Schweiz. <https://speicher.aeesuisse.ch/de/fokusstudien>
- Institut für Solartechnik SPF. (2024). *Ice-Grid*. Swiss Federal Office of Energy SFOE.
- KBOB (Ed.). (2022). *Ökobilanzdaten im Baubereich 2009/1:2022*. Koordinationskonferenz der Bau- und Liegenschaftsorgane der öffentlichen Bauherren. <https://www.kbob.admin.ch/de/oekobilanzdaten-im-baubereich>
- Kirchner, A., Kemmler, A., Ess, F., & Auf der Maur, A., Althaus, H.-J., Jakob, M., Müller, A. (2020). *Energiemöglichkeiten 2050+, Kurzbericht*. Prognos AG, INFRAS AG, TEP Energy GmbH, Ecoplan AG.
- QM Thermische Netze. (2025). Verenum AG im Auftrag von EnergieSchweiz.
- Röder, J., Meyer, B., Krien, U., Zimmermann, J., Stührmann, T., & Zondervan, E. (2021). Optimal Design of District Heating Networks with Distributed Thermal Energy Storages – Method and Case Study. *International Journal of Sustainable Energy Planning and Management*, 31, 5–22. <https://doi.org/10.5278/ijsepm.6248>
- Schädle, K.-H., Schmidt, T., & Berberich, M., Arndt, D., & Klingler, P. (2018). *Programm „thermische Netze“, Arbeitspaket „Einsatz von thermischen (saisonalen) Speichern in thermischen Netzen“*. EnergieSchweiz, Bundesamt für Energie.
- Schuchardt, G. K. (2017). Integration of Decentralized Thermal Storages Within District Heating (DH) Networks. *Environmental and Climate Technologies*, 18(1), 5–16. <https://doi.org/doi:10.1515/rtuect-2016-0009>
- Swiss Federal Office of Energy SFOE. (2024). *OPTIM-EASE* (Deliverable WP1 13.12.2022).
- Thermische Netze Schweiz TNS. (2026, March). *Thermische Netze Schweiz—Jahresbericht 2025*. https://www.thermische-netze.ch/fileadmin/user_upload/Dokumente/Publikationen/Downloads/Jahresbericht_2025.pdf
- Wirtz, M. (2023). nPro: A web-based planning tool for designing district energy systems and thermal networks. *Energy*, 268, 126575. <https://doi.org/10.1016/j.energy.2022.126575>



9 Appendix

9.1 Assumptions for the simulations in optihood

Table 12: Cost and greenhouse gas emissions assumptions of different Parameters in district heating networks.

Item	Costs				Greenhouse gas emissions		Source
Storage Tank (up to 2'000 L)	2840	CHF	0.605	CHF/L	0.44	kgCO ₂ -eq./L	(Bundesamt für Energie, 2021; Swiss Federal Office of Energy SFOE, 2024)
Storage Tank (2'000 to 20'000 L)	7550	CHF	0.827	CHF/L	0.38	kgCO ₂ -eq./L	(Swiss Federal Office of Energy SFOE, 2024)
DHN Pipelines KMR DN20			842	CHF/m			(QM Thermische Netze, 2025)
DHN Pipelines KMR DN25			889	CHF/m			(QM Thermische Netze, 2025)
DHN Pipelines KMR DN32			981	CHF/m			(QM Thermische Netze, 2025)
DHN Pipelines KMR DN40			1105	CHF/m			(QM Thermische Netze, 2025)
DHN Pipelines KMR DN50			1204	CHF/m			(QM Thermische Netze, 2025)
DHN Pipelines KMR DN65			1293	CHF/m			(QM Thermische Netze, 2025)
DHN Pipelines KMR DN80			1408	CHF/m			(QM Thermische Netze, 2025)
DHN Pipelines KMR DN100			1591	CHF/m			(QM Thermische Netze, 2025)
DHN Pipelines KMR DN125			1874	CHF/m			(QM Thermische Netze, 2025)
DHN Pipelines KMR DN150			2272	CHF/m			(QM Thermische Netze, 2025)
DHN Pipelines KMR DN200			2782	CHF/m			(QM Thermische Netze, 2025)
DHN Pipelines KMR DN250			3376	CHF/m			(QM Thermische Netze, 2025)
DHN Pipelines KMR DN300			4013	CHF/m			(QM Thermische Netze, 2025)
DHN Pipelines KMR DN350			4642	CHF/m			(QM Thermische Netze, 2025)
DHN Pipelines KMR DN400			5221	CHF/m			(QM Thermische Netze, 2025)
DHN Pipelines KMR DN450			5726	CHF/m			(QM Thermische Netze, 2025)
DHN Pipelines KMR DN500			6181	CHF/m			(QM Thermische Netze, 2025)



Item	Costs				Greenhouse gas emissions		Source
Biomass [*]			0.054	CHF/kWh	0.011	kgCO ₂ -eq./kWh	(Bundesamt für Energie BFE, 2024; KBOB, 2022)
Biogas [*]			0.12	CHF/kWh	0.12	kgCO ₂ -eq./kWh	(Bundesamt für Energie BFE, 2024; KBOB, 2022)
Natural gas			0.165	CHF/kWh	0.23	kgCO ₂ -eq./kWh	(Bundesamt für Energie BFE, 2024; KBOB, 2022)
Electricity (CH)			0.27	CHF/kWh	0.125	kgCO ₂ -eq./kWh	(Bundesamt für Energie BFE, 2024; KBOB, 2022)
Biomass Boiler ca. 200 kW	650	CHF /kW	1% Maintenance		93.43		(SWEET CoSi Deliverable D1.18; KBOB, 2022)
Solar Thermal Collectors ca. 200 m ²	910	CHF /m ²	0.5% Maintenance		127.03		(SWEET CoSi Deliverable D1.18; KBOB, 2022)

^{*} Only non-renewable emissions are taken into account here



9.2 Detailed results of THENA

The following figures show detailed results of the design of the adapted DHN in Landiswil (Chapter 5.2)

THENA_13d_DecenTGrids_v01_VV Landiswil.xlsx

Results graphs (page 1)

Assumptions for calculations

Characteristic values for pipe types according to QM district heating (default values)

Input parameter (E3) according to QM district heating (default value)

THENA_V1.3d_DecenTGrids_CH

Project: DistrictGrids

Variant: VV Landiswil

Leistungsoptimiert, Originale Leitung

Gebäude 10 (Strang 20)

Project manager: Stefan Thalmann

Date: 24.03.2026

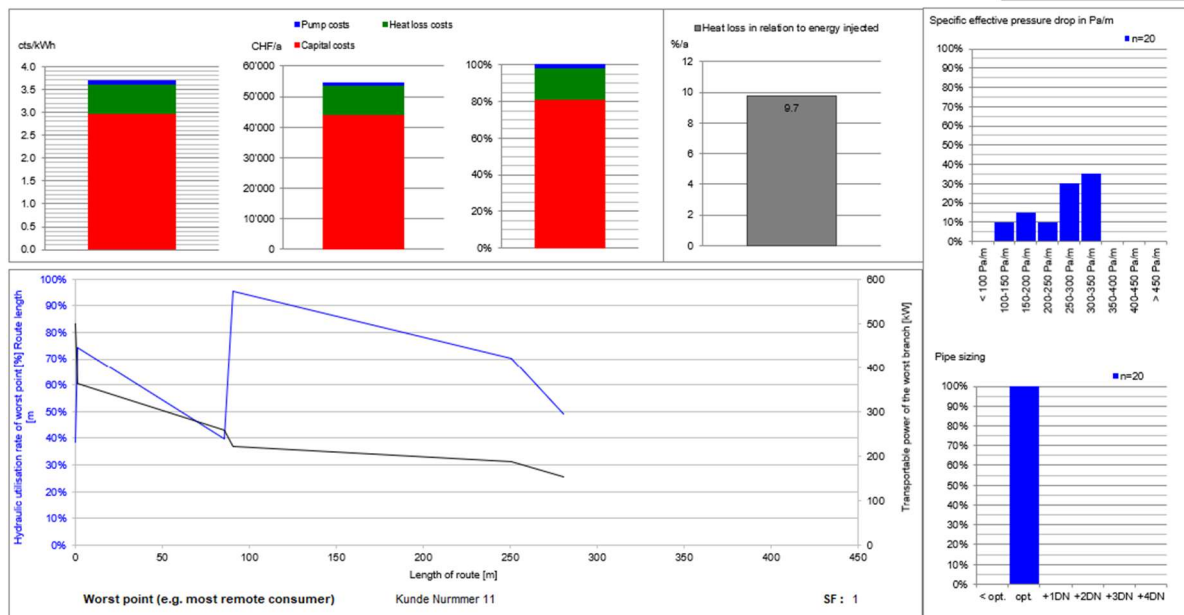


Figure 45: Results for costs, heat losses, pipe sizing, specific pressure drop and visualisation for the critical customer #11 with THENA for the Landiswil network as example.