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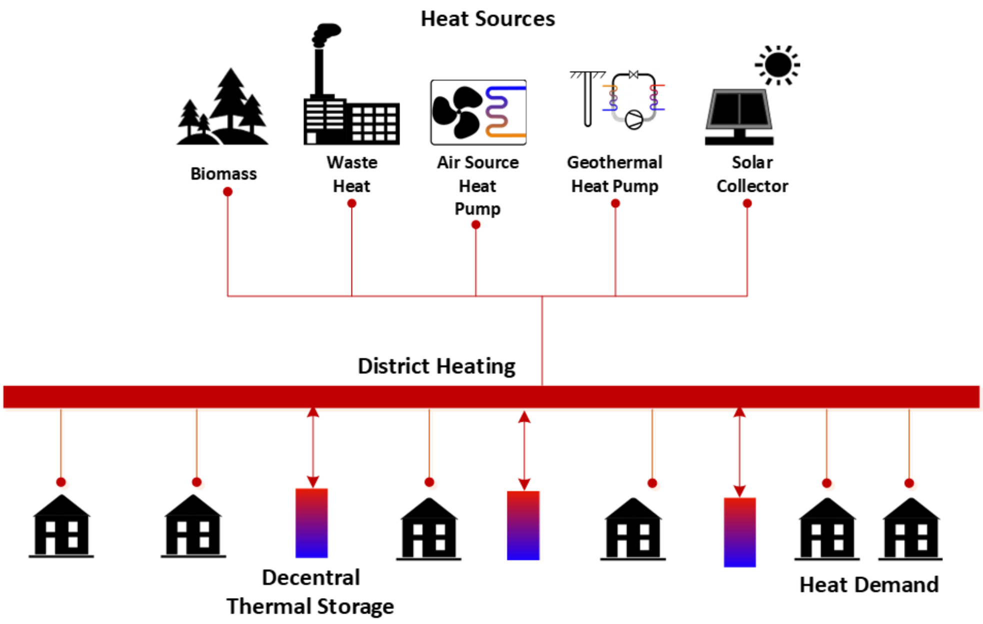
Federal Department of the Environment,
Transport, Energy and Communications DETEC

Swiss Federal Office of Energy
Energy Research and Cleantech

Interim report of 4 December 2024

DecenTGrids

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



Source: SPF, 2024

Publisher:
Swiss Federal Office of Energy SFOE
Energy Research and Cleantech
CH-3003 Berne
www.energy-research.ch

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SFOE contract number: SI/502748-01

Summary

Thermal storages for thermal grids can help to smooth out peak loads and to avoid or reduce the use of fossil back-up systems. Heat surpluses can be stored temporarily. Decentral storage systems in particular also make it possible to relieve the load on individual grid sections, or to enable grid densification and expansion. They are also ideal for the efficient integration of decentral heat sources. In this project, the possible cost and emission savings through the use of decentral thermal storage units in different district heating grids are quantified. In addition to recommendations for the dimensioning and operation of such storage units, an Excel user tool will be published, which will allow planners to determine the influence of storage units on the thermal load distribution and the costs of a thermal grid.

In the first project year, three typical thermal networks are chosen and defined by their heat demand, specific costs, and environmental impacts of components and operation. The approach for generating data on the effects of using (de-)central storages in the networks was adapted. The development of the tools used for generating data and for presenting the results for planners is ongoing.

Zusammenfassung

Thermische Speicher für Wärmenetze können dazu beitragen, Lastspitzen zu glätten und den Einsatz fossiler Spitzenlastkessel zu vermeiden oder zu reduzieren. Lastspitzen können geglättet und der Einsatz fossiler Spitzenlastkessel vermieden werden. Wärmeüberschüsse können zwischengespeichert werden. Insbesondere dezentrale Speicher lassen es auch zu, einzelne Netzabschnitte zu entlasten, bzw. Netzverdichtungen und Erweiterungen zu ermöglichen. Sie sind auch ideal für die effiziente Einbindung dezentraler Wärmeerzeuger. In diesem Projekt werden die möglichen Kosten- und Emissionseinsparungen durch den Einsatz dezentraler thermischer Speicher in unterschiedlichen Fernwärmenetzen quantifiziert. Neben Empfehlungen für die Dimensionierung und den Betrieb solcher Speicher, wird ein Excel-Anwendertool entwickelt, mit dem Planer den Einfluss von Speichern auf die Leistungsverteilung und die Kosten eines thermischen Netzes bestimmen können.

Im ersten Projektjahr werden drei typische Wärmenetze ausgewählt und durch ihren Wärmebedarf, ihre spezifischen Kosten und die Umweltauswirkungen von Komponenten und Betrieb definiert. Der Ansatz zur Generierung von Daten über die Auswirkungen des Einsatzes von (de-)zentralen Speichern in den Netzen wurde angepasst. Die Entwicklung der Werkzeuge zur Datengenerierung und zur Darstellung der Ergebnisse für Planer ist im Gange.

Résumé

Les systèmes de stockage thermique pour les réseaux thermiques peuvent contribuer à atténuer les pics de charge et à éviter ou réduire l'utilisation de systèmes d'appoint à base de combustibles fossiles. Les charges de pointe peuvent être atténuées et l'utilisation de systèmes d'appoint fossiles peut être évitée. Les excédents de chaleur peuvent être stockés temporairement. Les systèmes de stockage décentralisés, en particulier, permettent également de soulager la charge des sections individuelles du réseau, ou de permettre la densification et l'expansion du réseau. Ils sont également idéaux pour l'intégration efficace des sources de chaleur décentralisées. Ce projet quantifie les économies possibles en termes de coûts et d'émissions grâce à l'utilisation d'unités de stockage thermique décentralisées dans différents réseaux de chauffage urbain. En plus des recommandations pour le dimensionnement et l'exploitation de ces unités de stockage, un outil utilisateur Excel sera publié, qui permettra aux planificateurs de déterminer l'influence des unités de stockage sur la distribution de la charge thermique et les coûts d'un réseau thermique.

Au cours de la première année du projet, trois réseaux thermiques typiques sont choisis et définis en fonction de leur demande de chaleur, de leurs coûts spécifiques et de l'impact environnemental de leurs composants et de leur fonctionnement. L'approche pour générer des données sur les effets de l'utilisation de stockages (dé)centraux dans les réseaux a été adaptée. Le développement des outils utilisés pour générer des données et pour présenter les résultats aux planificateurs est en cours.

Contents

List of abbreviations

DHW	Domestic hot water
HP	Heat pump
MFH	Multi-Family House
SFH	Single-Family House
SFOE	Swiss Federal Office of Energy
SH	Space heating
THW	Terawatt hours

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 6.5 TWh today to 11 - 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 replace the still relevant fossil fuel share, which is currently around 23 % in Swiss thermal networks (VFS, 2022).

A promising option for the more rational use of heating networks is the increased use of thermal storage, in particular to reduce load peaks on different time scales, so that pipe diameters in the network can be reduced or that more consumers can be connected to a network. Further, as little unused surplus heat as possible can result, which is relevant e.g. for waste incineration plants or solar thermal systems in the summer months. Thermal storages are also a prerequisite for the integration of fluctuating renewable energy sources, such as solar thermal energy or PV & heat pumps.

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.

1.1.1.Current distribution of storages in thermal networks

Small centralized or decentralized storage facilities with capacities in the range of one hour of heat generation or consumption are already available in many places. These are essentially technical storage units. They are used, for example, to ensure that minimum running times of heat generators or pumps can be maintained. However, medium and large sized thermal storages for bridging longer periods of time (days, weeks, seasons), which are used specifically for energy management, are still rarely used in Swiss heating networks.

Central seasonal storage systems have already been covered in various studies, see e.g. Haller & Ruesch (2019), Schädle et al. (2018). The current SFOE project BigStoreDH[1] 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. There are also a number of examples of implementation. In Switzerland, these still tend to be at the superstructure or site level, such as the medium-temperature ground probe storage facility at EMPA (Schmid, 2022), low-temperature ground probe storage facilities such as at the Suurstoffi site in Rotkreuz (Vetterli et al., 2017) or large ice storage facilities such as in the ARK 147 superstructure in Bern (B-Solartec AG, o.J.).

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 possibilities of decentralized storage.

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[1] See www.spf.ch/BigStoreDH

1.1.2. Possible advantages of integrating storages in thermal networks

Medium to large thermal storage capacities – installed both centrally and decentrally – 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.
- 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. Also, flexibility for the operation of heat pumps in case the COP or the CO_2 footprint of the electricity mix are changing in the time scale of the storage capacity.
- 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 also offer the following possibilities:

- Reduction in the capacity of the distribution grid (line cross-sections, transfer stations), or more expansion potential.
- Reduction 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

1.2 Project objectives

This project aims to answer the following overarching questions:

- To what extent and through what savings can the costs and CO_2 emissions of heat supply via thermal networks be reduced through the use of decentralized thermal storage?
- What are the optimal dimensions for the different types of decentralized storage in typical heating networks (especially warm networks with waste heat from waste incineration plants or biomass and networks with heat pumps)?
- Which simple operating strategies for decentralized storage systems can be used to smooth load peaks in the heating network (especially the daily morning peaks)?

In particular, mathematical optimization calculations are carried out to answer these questions.

The project should also result in an Excel 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.

2 Approach / Method

The methodological approach in the project is currently still being discussed and adapted by the project partners. It has turned out to be challenging to develop a direct interface between the optihood tool and the THENA tool. We now want to use the 'TSA Tool', another Excel-based hourly calculation tool that was developed at the SPF in the past, to analyse the effect of thermal storage on the performance of peak load boilers. With the TSA tool, the load peaks can be minimised for individual branches of a network that have a storage facility at a central or decentralised location, so that the use of peak load boilers is minimised. The power peaks in the network are also minimised accordingly.

Series optimisations using the TSA tool will be used to determine reduction factors that can be used in THENA to estimate the influence of the installation location and size of thermal storage units on component sizes and costs. A simplified version of this tool could be published as a final result in the end of the project together with the opensource version of the pipe sizing tool THENA. A combination of these two simples Excel based tools could allow to analyse the effect of decentralized TES in the sizing of network pipes.

The customised optihood tool will then also be used to quantify the effect of the storage tanks for the same networks. Subsequently, the results of optihood and the two Excel tools will be assessed in a comparison of methods in order to check the plausibility of the results.

The work packages according to the proposal are as follows:

- **WP 1 – Representative heating networks:** Three or four representative heating networks are defined, i.e. their type, topology, spatial data and heat demand profiles of all consumers
- **WP 2 – Boundary conditions**: Assumptions for costs and CO_2 emissions of all relevant system components and energy sources have been made and agreed with the support group
- **WP 3 – System optimizations with optihood optimization software:** Extension of the optihood software with the DHWx package for the optimization of thermal networks, Determination of optimal storage dimensions for various typical heating networks and various target criteria, Comparison and evaluation of simple storage loading strategies
- **WP 4 – Development of Excel user tool:** Creation of a user-friendly Excel tool to determine the potential of decentralized heat storage in existing or planned heating networks, Validate the Excel tool with the results from the Python-based optimization calculations.
- **WP 5 – Case studies:** Demonstration of both the Python-based optimization calculations and the Excel user tool for determining the potential of decentralized heat storage in real-world applications.

3 Definition of the heating networks and general framework

3.1 Representative heating networks

The BigStoreDH[2] project contains an analysis of the heating networks in Switzerland. The majority of the Swiss district heating networks are powered by wood. Networks powered by heat pumps and environmental heat representing the type of networks with the largest growing rate and potential. In contrast, the greatest quantity of energy is distributed by grids connected to waste incineration plants. The data

[2] See www.spf.ch/BigStoreDH

obtained from this analysis was used to define three typical and generic thermal networks, which represent the variety of networks in Switzerland. In addition to the energy source, the size of the networks was defined in terms of power, length, temperature levels, and topology. These three representative networks are shown in Table 2.

Table 1: Representative three thermal networks in Switzerland with their parameters.

	Biomass	Environmental heat	Waste heat
Power [MW]	0.9	3.7	23.3
Demand [GWh]	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 branchs	Mesh
Number of connections	21	32	573

The modelling and optimising of networks comprising over 500 connections is too complex for the Optihood tool. Consequently, only the smaller biomass network is modelled and used as a single branch of the larger networks, too. It is necessary to modify the cost functions of the components and certain other parameters in case the biomass network is used as branch of a larger network.

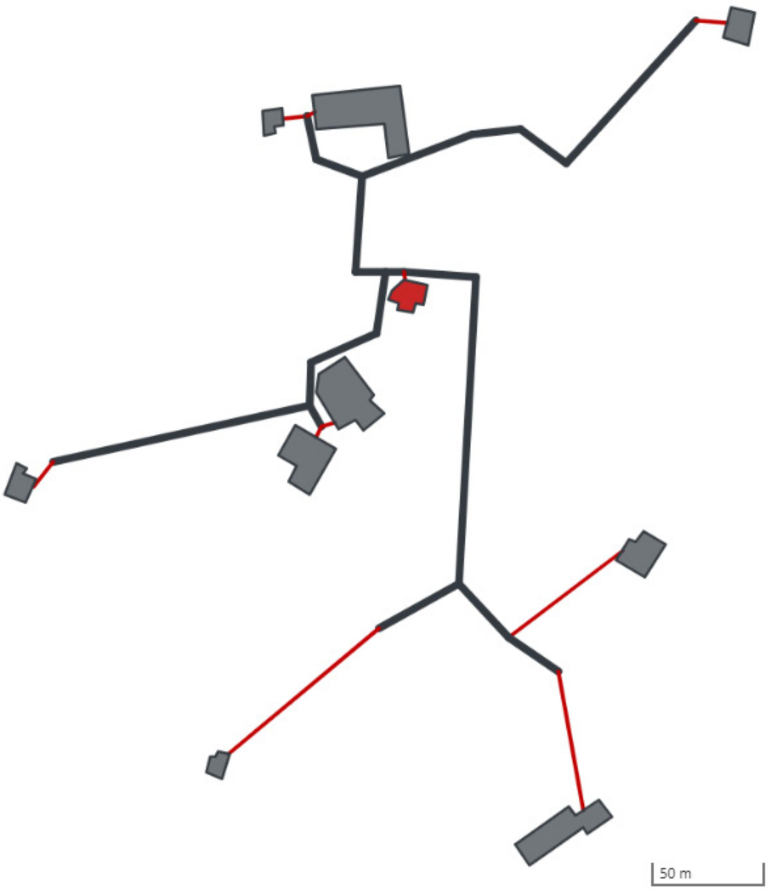

Figure 1: Biomass district heating network in Landiswil with ten buildings.

As a typical biomass network, the district heating network in Landiswil was utilized for modelling. A partner of the advisory board could provide the consortium with data and information on this network. The network comprises ten buildings. One of the buildings is a school, one an office building and the remainder are residential buildings with a variety of apartment sizes. The network is powered by wood and extends 1.1 km, with an estimated heating demand of approximately 560 MWh and a temperature level of 65°C. The buildings are assumed to be old and thermally not well isolated. Figure 2 illustrates the network structure. Most of the buildings have space heating and domestic hot water demand. Additionally, most buildings have supplementary storage systems installed or the capacity to install a storage in the future.

3.2 Demand profiles

In order to generalize results typical profiles for the hot water demand as well as the space heating demand of each building were generated using nPro (*NPro App*, n.d.). The calculations are based on the values in Table 3 (from nPro) for the different buildings and the respective energy reference areas of the various buildings. The calculations for the domestic hot water are based on a consumption of 21 kWh/m²/a for the residential building, 3 kWh/m²/a for the school and in the network example used, the office building does not have a hot water demand covered by the network. The space heating demands of the residential buildings depend on the age of the building, as well as the type (MFH, SFH) and are in the range of 15 to 244 kWh/m²/a. They are also dependent on the climatic region. In our case, an average reference year in Bern is used. The thermal building standards in the network have not yet been finalised and the assumed specific maximum consumption will be compared and adapted to real user data.

Table 2: Space heating and hot water demand values for the calculation in nPro.

	Space heating demand [kWh/m2/a]	Domestic hot water demand [kWh/m2/a]
Residential building	15 - 244	21
School	122	3
Office	127	-

Figure 3 illustrates the hot water demand distribution over the course of one year, with an example of the biggest residential building, a school and the total network. The demand for hot water is lower during the summer months and weekends, holidays are also considered (especially in the school building).

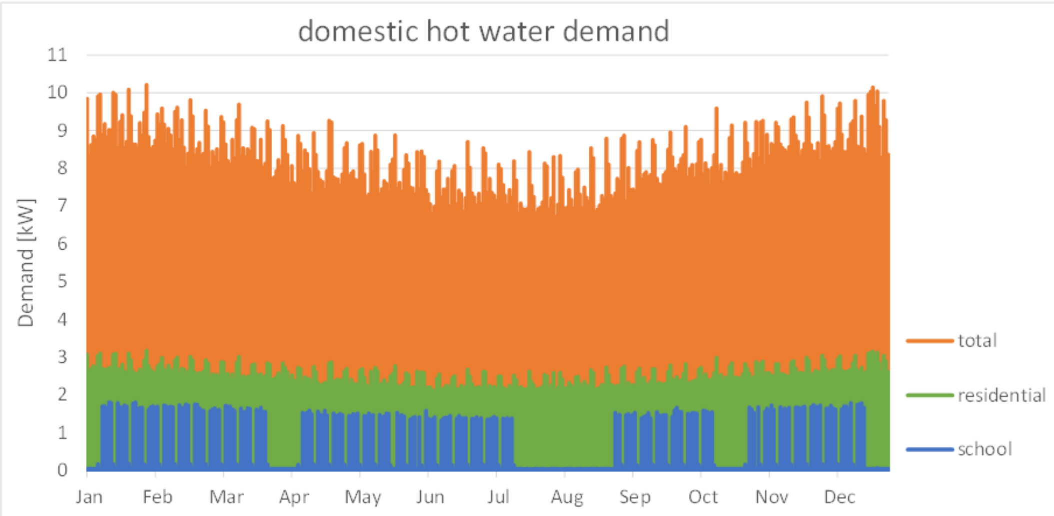

Figure 2: Annual domestic hot water demand of a school building, one residential building and in total.

The daily hot water demand is shown in Figure 4 with Sunday and Monday in January as examples. The daily demand of the residential building indicates a morning and an evening peak, with an increase at weekends. The school building doesn't have any hot water demand at the weekends and during holidays. There is a peak during school hours on weekdays in the school.

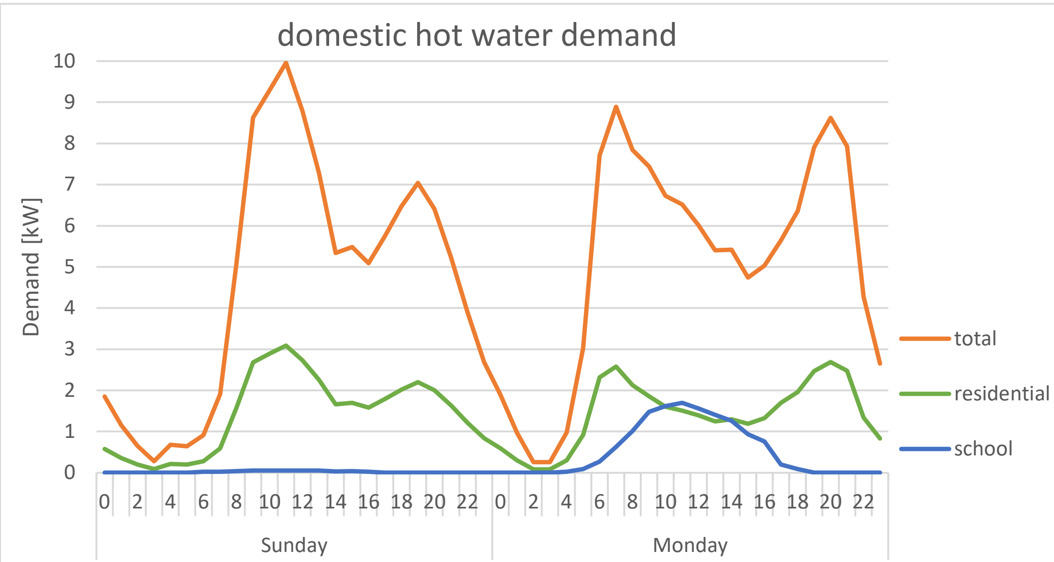

Figure 3: Daily domestic hot water demand of school a building, one residential building and in total.

Figure 5 illustrates the space heating demand of the network in total, of the office building, the school and of one residential building over one year. As usual, the demand in summer is very low and high during the winter with more fluctuations in the school and the office building, compared to the residential buildings.

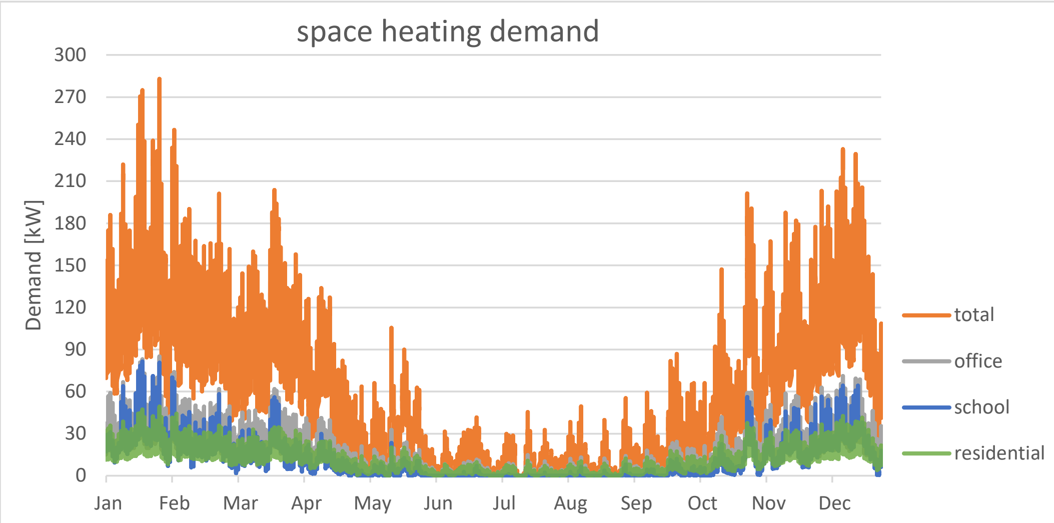

Figure 4: Annual space heating demand of a school building, one residential building, an office and in total.

Figure 6 shows the typical space heating demand during two days in January, for Sunday and Monday. The residential buildings have two peaks per day, one in the morning and one in the evening. The school has similar peaks, with a bigger peak in the later morning. The office building has solely one peak in the morning. Furthermore, the total space heating demand in the network is also higher on Monday as the outdoor temperature is also lower on that day.

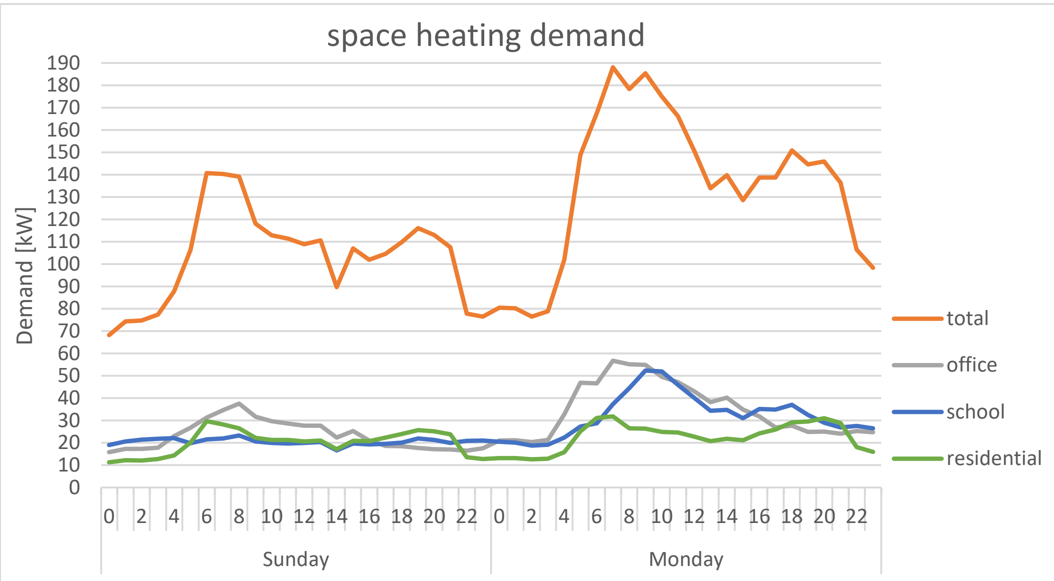

Figure 5: Daily domestic hot water demand of a school building, one residential building, an office and in total.

The total heating demand of the network amounts to 560 MWh/a with a share of the hot water demand of about 7% and a share of the space heating demand of 93% accordingly. The total peak in the network goes up to 290 kW (not shown here in the graphics) and the highest peaks are coming from the space heating demand of the school and the office building, as shown in Figure 7. In the figure, the yellow bars show the residential buildings, and the green one is the residential building used for the example in the figures before. This demand profiles are not final and need to get validated.

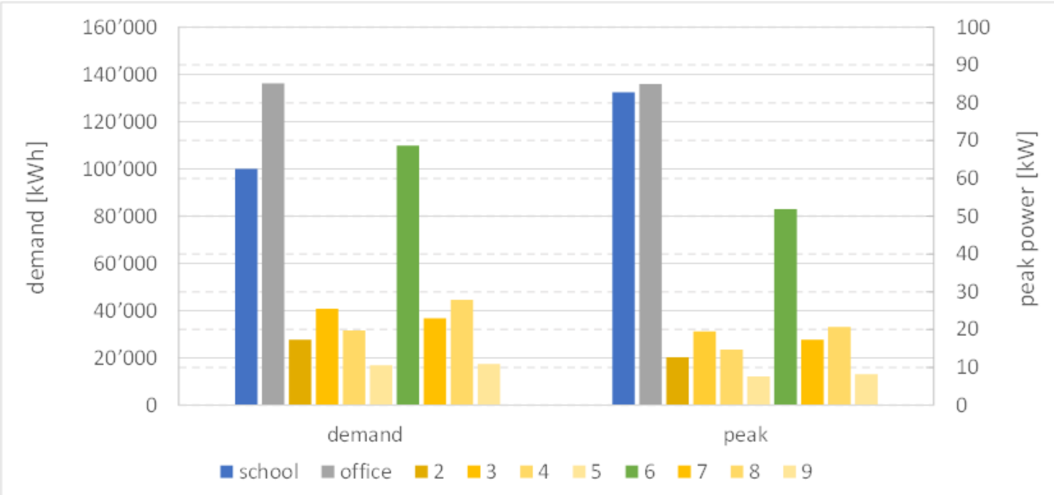

Figure 6: Heating demand and peaks of every building in the biomass network.

As an alternative to using fixed profiles for space heating, one could model the building using a combination of thermal resistances and capacities (thermal inertia) of the building spaces. A building, in this context, consists of three thermal elements: (i) heat distribution, (ii) indoor air mass, and (iii) building wall/envelope (including building mass). Each element is represented using a thermal resistance and a thermal capacity, leading to a 3R3C building model (Péan et al., 2017). Furthermore, thermal energy gains/losses through windows and internal gains due to occupancy (people and equipment) are also considered. This model is already implemented within our optimization framework and allows the optimizer to shift the demand while maintaining a pre-defined indoor temperature range. In order to setup the building model, we need to fit the thermal resistances and capacities for each thermal space such that the building's space heating demand matches the given demand profile. The parameters of building model are currently being tuned for each of the 10 buildings considered in the biomass network.

3.1 Assumptions for costs and greenhouse gas emissions

The assumptions regarding the costs and greenhouse gas emissions are presented in Table 5. The costs associated with decentralised and centralised 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. The initial investment costs for centralised storage solutions are significant, whereas the costs per litre are relatively modest. Consequently, the investment required for a large storage facility is not significantly influenced by the size of the facility itself, but rather by the decision to construct it. In contrast, the decentralised storage system is characterised by a high degree of cost dependency on the size of the storage facility, with the choice of size having a significant impact on the overall cost. The cost of pipelines is also dependent on their 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.). Network of a limited scale result in costs being applied for a relatively small diameter of pipes. Data of other pipe diameters and installation situations are in the appendix. Due to the effect of inflation on the prices of pipes and construction, as the cost data is not up to date, the figures have been adjusted by a factor of 1.25 based on the experience of the project partner Verenum .

The CO_2 emissions are average values within the range of potential storage sizes, given that the emissions per litre vary with the differing sizes. The emissions associated with biomass and natural gas are solely attributable to the fuel itself and do not include any additional emissions resulting from the production of the heating centre or pipes. These emissions are accounted for by different components within the modelled system.

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

	Costs				greenhouse gas emissions		Source
Decentral Storages (DHW) (200 - 2'000 litre)	2'132	CHF	6.88	CHF/litre	0.70	$kgCO_2$-eq./litre	(Bundesamt für Energie, 2021; Swiss Federal Office of Energy SFOE, 2024)
Central Storage (HW) (< 37'000 m^3)	292'628	CHF	0.0595	CHF/litre	0.38	$kgCO_2$-eq./litre	(Bundesamt für Energie, 2021; Institut für Solartechnik SPF, 2024)
Pipelines (DN20)	560	CHF/m	21'000	CHF/kW			(QM Fernwärme, 26)
Biomass			0.106	CHF/kWh	0.025	$kgCO_2$-eq./kWh	(Bundesamt für Energie BFE, 2024; Koordinationskonferenz der Bau- und Liegenschaftsorgane der öffentlichen Bauherren KBOB, 2022)
Natural gas			0.15	CHF/kWh	0.23	$kgCO_2$-eq./kWh	(Bundesamt für Energie BFE, 2024; Koordinationskonferenz der Bau- und Liegenschaftsorgane der öffentlichen Bauherren KBOB, 2022)

More values of general parameters not related to the biomass network are in the appendix.

4 Calculation tools for assessing the effect of decentral storages

4.1 TSA-Tool – Sizing tool with hourly time step

The Excel-based TSA-tool[3], which employs hourly time steps, is designed for the purpose of dimensioning a storage in a heating network. The tool was originally developed at SPF for the SwissSTES[4] project for one central storage. In this project, a simplified and modified version was employed for the calculation of peak power in pipes with a decentral storage. Furthermore, a "predictive" control strategy for minimizing this peak power in the network was implemented, which intends to approximate the optimized control strategy of optihood. The values of the various heat generators are calculated on an hourly basis, considering the demand on the one hand and the storage discharge, its charging level, losses and the power of two base load heat generators and one peak load heat generator on the other. The tool calculates only the energy flows between the components and the demand coverage. This approach offers a

[3] TSA: Thermische Speicher Auslegung
[4] https://www.swissstes.ch/

simplified method for calculating the impact of a storage of a given size on the different loads and energy flows.

The hourly value calculation is based on the following assumptions and calculation methods:

Losses: In terms of the storage losses, it is assumed that the storage unit has a cylindrical shape and is exposed to the outside air with an insulated outer surface.

Storage modelling: The calculation of the storage charging level is based on the amount of discharge, charging and losses. The storage tank comprises three distinct layers, each representing a specific capacity and temperature. The lowest layer represents the return temperature of the network, the middle layer the flow temperature, and the uppermost layer the temperature at which the storage tank is at its maximum temperature. The power output of the storage tank for charging is not constrained, except by the level of charge itself. To guarantee a realistic storage initialization, a two-years calculation is performed, with only the second year being used for the analysis.

Weather forecast: In order to get results comparable to the optimized modelling in optihood, a similar "predictive" control was implemented. To implement this, the tool calculates the energy needed from the storage in the upcoming two weeks and the according average charging level needed in every hour. If the storage level is lower than this needed limit, it doesn't discharge it, except if it base and peak load heat generators are not enough to cover the demand in this hour.

Heat generator: In order to calculate the produced heat, it is necessary to consider both the base load and the peak load heat generator. The heat requirement is consistently met by the base load heat generators. In the case of insufficient heat, the storage tank is utilized as a source, and if necessary, the peak load heat generator is employed to supply the energy. The remaining storage capacity may be charged by the base load and the peak load heat generator, with the remaining capacities. The model does not include any inertia, control levels or minimum output specifications.

In Figure 7 is an example of the annual heat supply of the biomass network with only one base load heat generator calculated in the Excel tool. The size of the base load heat generator, peak load heat generator and storage are not real values. In this example, the base load heat generator works on full power except for the summer and autumn. In the light green tone, the base load heat generator charges the storage, which gets charged especially in spring with the remaining power until it is full. The energy from the storage gets used in winter and in early spring, the storage is empty and the peak load heat generator needs to cover peaks by itself and there is one small time without coverage of the demand (grey).

Power in pipes: The energy flows between the components get calculated and they get assigned to the main pipe. The tool cannot calculate several parallel branches, which is why, in case there are several consumers, they all must be aggregated into a single value. If different branches should be analysed, the tool needs to be used several times with the respective demand of each branch. Figure 8 provides an overview of the network calculation principle, illustrating two approaches of thermal storage integration, once a central and once a decentral approach. In the case of a central storage system, the maximal power in the main pipe equals the maximal demand. The storage serves to cover peaks in demand, thereby minimizing the need for a larger source of energy. In case of a decentral storage, the charging of the storage facilities, as well as the direct coverage of the demand through the generators, occurs via the main pipe. The discharge of the storage facility helps meeting the demand and peaks do not have to be transmitted by the main pipe. Consequently, the maximum power in the main pipes consists of the charging of the storage as well as the partial direct coverage of the demand and with a large decentral storage this maximum in the pipe is lower than the maximal demand.

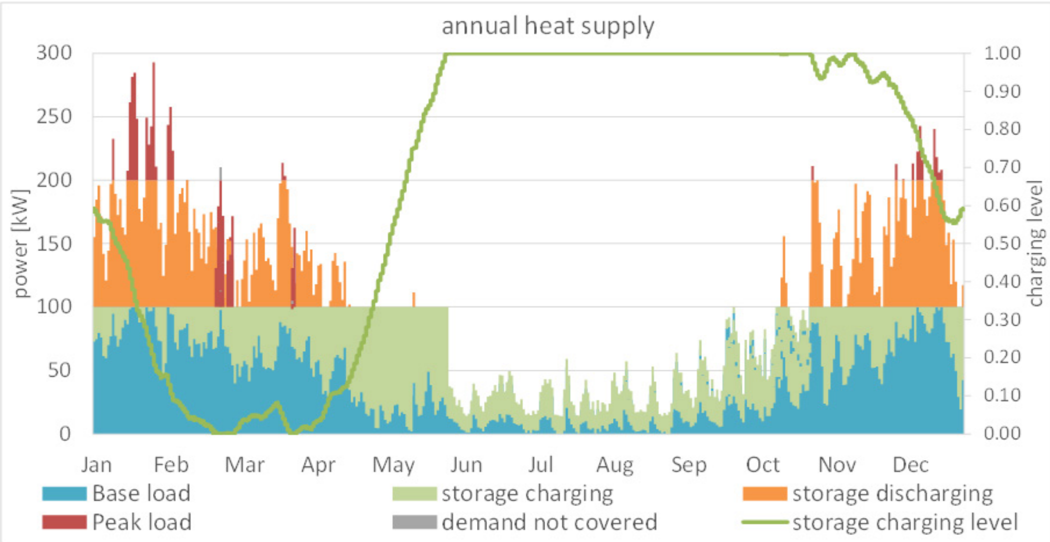

Figure 7: Example of calculated annual heat supply in Excel tool for a small network.

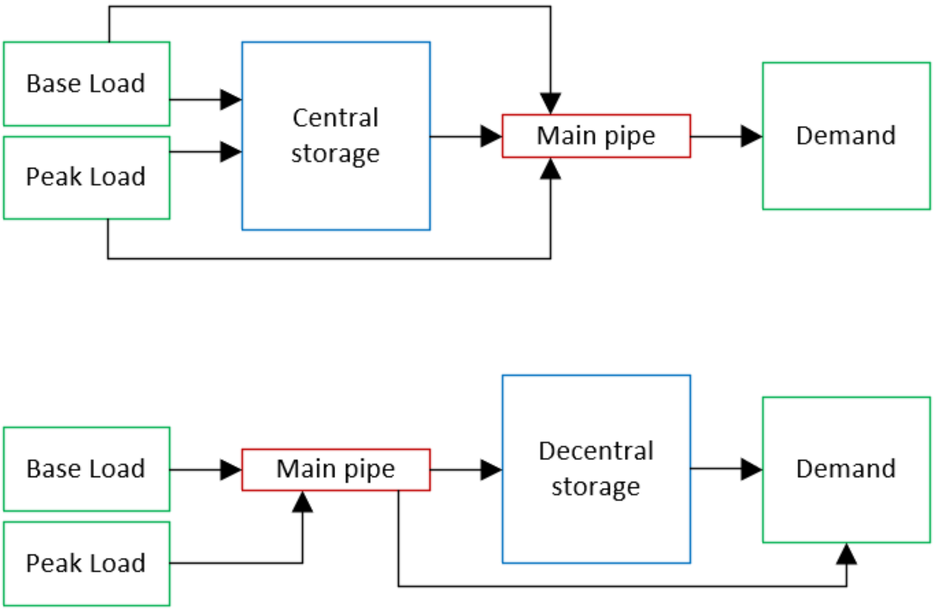

Figure 8: Principle of the network calculation of the decentral and central storage in the Excel tool.

Excel solver: As the storage charging power is not limited in the Excel tool and the strategy of the heat generator is to charge the storage with free capacities, the maximal power in the main pipes in case of a decentral storage is directly dependant of the heat generator power. The Excel solver is implemented to optimize the peak load heat generator size (for a given storage size), so the power in the main pipe is as low as possible but still gets the demand covered.

It should be noted that the calculation method does not account for certain effects. The main pipe and distribution lines are aggregated, so parallel distribution pipes or branches need to be sized with separate tool runs. A similar situation arises with the calculation of demand and storage, which both must be aggregated. Furthermore, it must be considered that the thermal power after the storage could potentially exceed the power in the main pipe with a large, decentralised storage. Consequently, the tool calculates values in a general manner and does not provide detailed results. Additionally, the topology and pressures are not modelled. If there are multiple storages in a row or parallel in a network, this tool can only calculate the peak power decrease of one pipe before one storage.

The goal of this calculation of the network system, particularly the power within the pipes, is to identify a correlation between the size of decentralised storage and the reduction of power through the pipes. The reduction of power in the pipes could be used as an input in THENA and consequently results in the choice of pipes of a smaller diameter, which would result in a reduction in costs.
It must be determined whether it is feasible to establish a reduction factor correlating with storage size and to establish a generalised formula for its application. It is also necessary to figure out on which additional parameters this reduction factor is dependent. Furthermore, the accuracy of the calculations must be validated.

Figure 10 illustrates an example of a decentral storage in the biomass network. In this case there are three buildings on one branch connected with the rest of the network through a main pipe (in green) and with a decentral storage (in blue). The maximal power through the main pipe gets reduced by the decentral storage. The extent of this reduction of maximal power in the main pipe is shown in Figure 11.

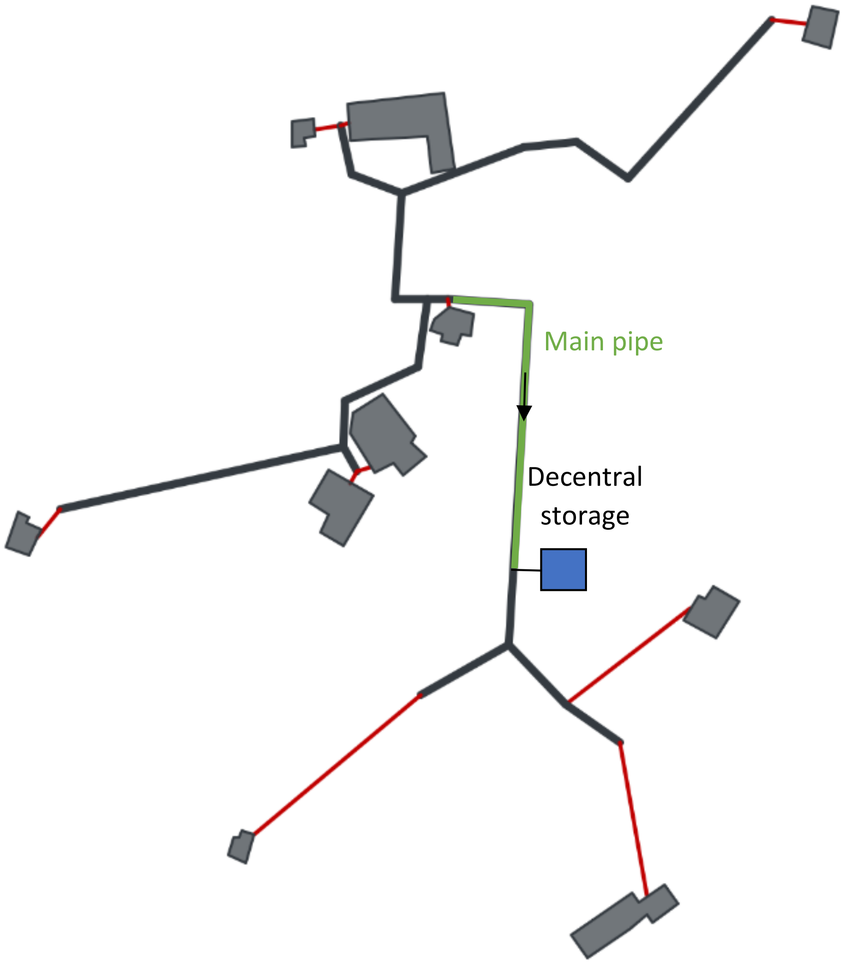

Figure 9: Example for locating a decentral storage in one of the branches of the biomass network.

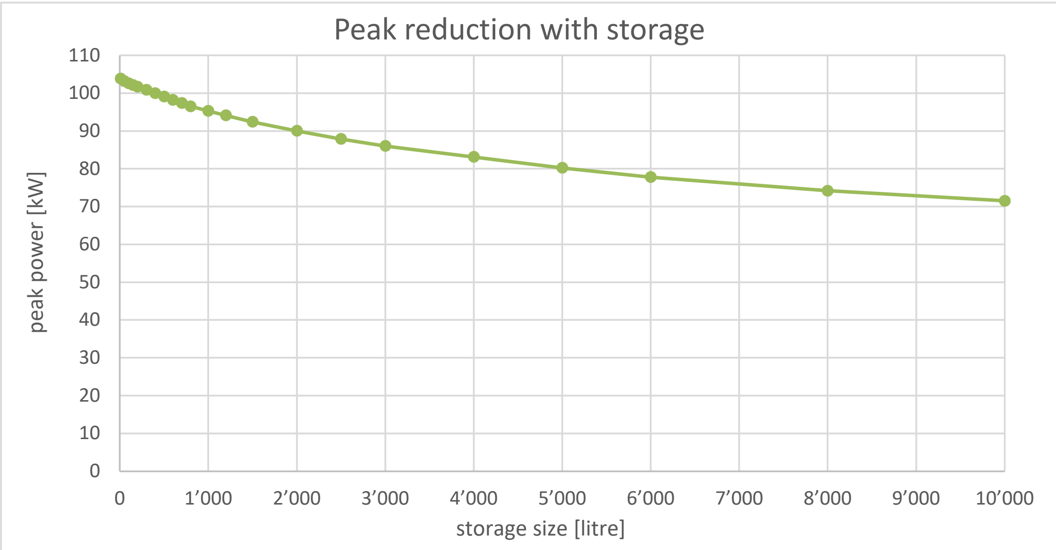

Figure 10: Maximal power in the main pipe with different decentral storage sizes for the above shown example branch.

4.2 Extension of the optihood optimization framework

The optimization framework, optihood (Dimri et al., 2023), is an open-source python package developed at SPF to define and optimize energy networks. The framework uses mixed-integer linear programming (MILP) to model different components of an energy network such as energy sources, sinks (or demands), energy conversion and storage technologies. These components could either be available to specific buildings or to the entire network. In addition, it is possible to model thermal and electrical connections (referred to as links) between the buildings to share the produced thermal energy and electricity. Once the available components of an energy network have been defined, the framework makes use of the oemof python package, which in turn uses pyomo to formulate a mathematical optimization problem (i.e. a set of given parameters, constraints, decision variables and objective/target function). The problem could then be solved by using any solver such as gurobi, cbc, glpk, which is compatible with pyomo, with the goal of minimizing or maximizing the objective/target function.

The target of optimization could be either to minimize the costs or to minimize the total emissions. In case of cost minimization, both the investment cost (annualized) and operation cost are considered in the optimization target. When the goal of optimization is to minimize the emissions, the optihood framework considers the emissions from operation (e.g. use of biomass) and the annualized embodied emissions of the installed energy conversion/storage technologies. These two optimization targets are implemented in optihood, while the framework could be extended as needed to include other targets such as peak load minimization.

The next subsections describe the extensions made to optihood within this project.

4.2.1. Thermal grid

The existing model of thermal grids in optihood is a node which balances the energy inflow(s) with the energy outflow(s). This model allows definition of losses per kWh of energy inflow/outflow through the thermal grid. For e.g., 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 energy inflows to the thermal grid node could come directly from energy sources (e.g. a biomass boiler) or through a central thermal energy storage. While, the energy outflows transfer the incoming energy either to individual buildings or to decentral storages.

To evaluate the cost of thermal grids, it is possible to assign a base investment cost and a cost per peak energy load (kWh) for each output flow from the thermal grid node. Assigning costs to each peak output flow would be reasonable if each output flow represented a network branch, but not when individual buildings are connected to the output flows. Therefore, it was decided to assign a cost to the total peak energy inflow to (or total peak energy outflow from) the thermal grid node.

The existing model was, therefore, extended to assign a cost for the peak total energy inflow, which would in turn represent the peak load which the district could deliver.

4.2.2.Visualization of optimization scenario

As part of the project work, a visualization module was implemented within optihood to make it easier to understand the connections between different components when modelling an energy network. Earlier, this had to be done using an input excel file, where each sheet described a specific type of component, and the rows within the sheets showed how a particular component was connected. This would mean, in order to understand the entire network, one would need to parse through all the sheets of the input excel file while checking different rows to see which component was connected where in the network. This was generally time-consuming and error-prone when modelling new networks or modifying existing network connections.

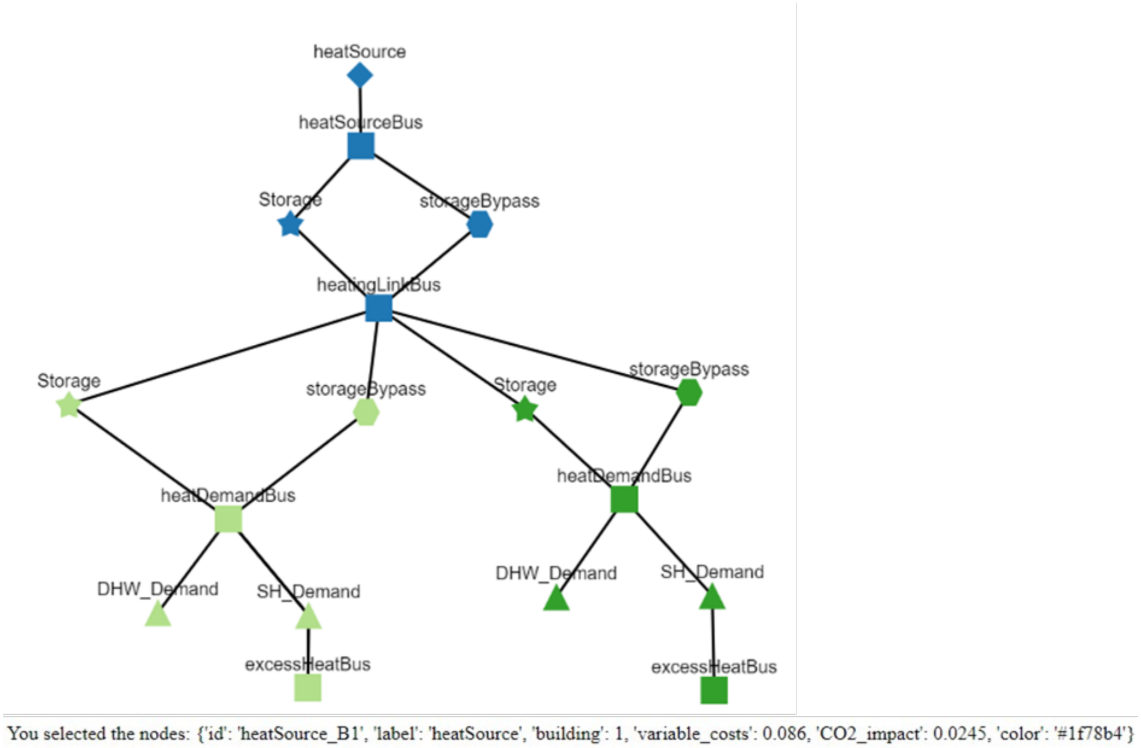

Figure 11: Graph network representing a scenario with three buildings (in blue, light green and dark green). The first building (blue) acts as a heat producer (heat source and storage) while the other two buildings act as consumers (storage and heat demand).

In order to simplify this process, we implemented a visualization module in optihood that reads the input Excel file and creates an interactive graph network showing all the connections between different components as well as the parameters set for each component (e.g. cost assumptions, minimum/maximum allowed installation capacity, etc.). The parameters of each component can be viewed by clicking that component in the interactive graph network. Figure 9 shows a graph network, created by the visualization module of optihood, with three buildings (each colour in the graph denotes a different building), where one building (blue) has a heat source together with a thermal energy storage, while the other two buildings each contain a storage and serve as heat sinks (with space heating and domestic hot water demands). In the illustrated scenario, space heating demands are modelled dynamically using a building model (see section 3.2), and therefore have a possibility of rejecting excess heat in summer. The parameters related to the heat source (e.g. cost in CHF/kWh and greenhouse gas emissions in $kgCO_2eq/kWh$) are activated by clicking on it and are shown at the bottom of the graph network.

5 Extension of the network sizing tool THENA

The task 4.1 requirement profile was started a little behind schedule. A first workshop was held on 25 October 2024. Initial ideas are available on how the excel-tool THENA can be expanded to illustrate the influence of thermal energy storage tanks. The aim is to enable a technical and economic assessment of the design of the heat distribution network when thermal energy storage tanks are installed.

The desired range of functions was roughly defined at the workshop (input data as well as output and illustration of results). The first draft is to be completed by the end of 2024 / January 2025. The excel tool should continue to be easy to use and comprehensible (without macros). As a result of this workshop, it has been decided to use and possibly combine the hourly based TSA Excel calculation tool with THENA.

6 Conclusions and outlook

The selection of typical heating networks to be analysed in the project was agreed with the advisory group. For the small biomass network a similar real network was identified, from which the network topology and geographical distribution of the single consumers could be adopted. The selected small biomass network will be used for itself and also as a typical branch of the two larger networks, the HP network and the waste heat network. There then with different line lengths and specific component costs and impacts. Load profiles were created generically using the nPro software. The load profiles for the space heating of the buildings can also be simulated in optihood using thermal building models if required.

Demand profiles of the space heating of the buildings of the biomass network in Landiswil are subject to further investigations and possibly adapted to measured data of the real network. However, the permission to use and publish measured data could not yet been secured.

The decision on the exact procedure for adapting the THENA design tool is still pending. The consortium has discussed the procedure intensively. It was decided to use the TSA tool, another Excel-based design tool that was previously developed at SPF and has now been adapted so that adjustment factors for THENA can be determined using series optimisations. After integration into THENA, it will be possible to determine the influence of decentralised storage systems on relevant indicators.

In a next step, the SPF will make an initial version of the adjustment factors available to Verenum so that the adjustments to the THENA tool can be tested. Furthermore, results from the Excel based TSA-tool will be compared to optihood.

It is planned to hold an advisory board meeting in the first quarter of 2025 to discuss the interim results and also possible application of the tool under development in case studies.

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8 Appendix

Table 4: Cost and greenhouse gas emissions assumptions of different Parameters in district heating networks.

Item	Costs				Greenhouse gas emissions		Source
Decentral Storages (DHW) (200 - 2’000 litre)	2’132	CHF	6.88	CHF/litre	0.70	$kgCO_2$-eq./litre	(Bundesamt für Energie, 2021; Swiss Federal Office of Energy SFOE, 2024)
Decentral Storages (HW) (300 - 5’000 litre)	1’092	CHF	1.408	CHF/litre	0.49	$kgCO_2$-eq./litre	(Swiss Federal Office of Energy SFOE, 2024)
Central Storage (< 36’843 m3)	292’628	CHF	0.0595	CHF/litre	0.38	$kgCO_2$-eq./litre	(Bundesamt für Energie, 2021; Institut für Solartechnik SPF, 2024)
Pipelines (DN20)			341	CHF/m			(QM Fernwärme, 26)
Pipelines (DN25)			349	CHF/m			(QM Fernwärme, 26)
Pipelines (DN30)			389	CHF/m			(QM Fernwärme, 26)
Pipelines (DN40)			411	CHF/m			(QM Fernwärme, 26)
Trenches terrain			125	CHF/m			(QM Fernwärme, 26)
Trenches street			250	CHF/m			(QM Fernwärme, 26)
Biomass			0.106	CHF/kWh	0.0245	kgCO2-eq./kWh	(Bundesamt für Energie BFE, 2024; Koordinationskonferenz der Bau- und Liegenschaftsorgane der öffentlichen Bauherren KBOB, 2022)
Natural gas			0.15	CHF/kWh	0.23	kgCO2-eq./kWh	(Bundesamt für Energie BFE, 2024; Koordinationskonferenz der Bau- und Liegenschaftsorgane der öffentlichen Bauherren KBOB, 2022)
Electricity (CH)			0.262	CHF/kWh	0.125	kgCO2-eq./kWh	(Bundesamt für Energie BFE, 2024; Koordinationskonferenz der Bau- und Liegenschaftsorgane der öffentlichen Bauherren KBOB, 2022)
Waste heat					0.00325	kgCO2-eq./kWh	(Bundesamt für Energie, 2021)
Gas boiler	8832	CHF	164	CHF/kW	93.43	kgCO2-eq./kW	(Swiss Federal Office of Energy SFOE, 2024)
Biomass boiler	18475	CHF	484	CHF/kW	93.43	kgCO2-eq./kW	(Swiss Federal Office of Energy SFOE, 2024)
Air source heat pump	15723	CHF	2185	CHF/kW	281	kgCO2-eq./kW	(Swiss Federal Office of Energy SFOE, 2024)
Ground source heat pump	20349	CHF	914	CHF/kW	146	kgCO2-eq./kW	(Swiss Federal Office of Energy SFOE, 2024)
Ground source heat pump with boreholes	19700	CHF	4000	CHF/kW	700	kgCO2-eq./kW	(Swiss Federal Office of Energy SFOE, 2024)

9 Project progress (confidential)

9.1 General project status and budget

As announced at the autumn meeting of the SPF on 22 October 2024, the work of the SPF is currently behind schedule due to a staff shortage in the optihood optimiser area in the first half of 2024. This bottleneck has been resolved since the summer. Attempts are now being made to catch up.

Verenum's work on the THENA Excel tool only started in October with a delay of approx. 3 months due to the SPF backlog.

The project team wants to catch up as much as possible and also organise another advisory board meeting in February 2025. At this meeting, the status of the further developments will be discussed with regard to their later applicability and the possibility of case studies, and their financing will be discussed. Sufficient content-related preparatory work in accordance with the project plan must be carried out before the monitoring group meeting.

The project budget was utilised to a reduced extent in line with the delays in the content-related work.

Table 5: Timetable according to the project application.

	2024												2025							
Milestones ⊙	Jan M1	Feb M2	Mar M3	Apr M4	May M5	Jun M6	Jul M7	Aug M8	Sep M9	Oct M10	Nov M11	Dec M12	Jan M13	Feb M14	Mär M15	Apr M16	Mai M17	Jun M18	Jul M19	Aug M20
AP 1: Repräsentative Wärmenetze		⊙	⊙																	
Task 1.1 Definition typischer Netze																				
Task 1.2 Generieren von Bedarfsprofilen																				
AP 2: Randbedingungen					⊙															
Task 2.1 Kostenannahmen																				
Task 2.2 Daten für die CO2-Bilanzierung																				
AP 3: Systemoptimierungen mit Python-optihood							⊙								⊙					
Task 3.1 Python-basierte Optimierungssoftware																				
Task 3.2 Auslegungsopti. von Netzen mit dez. Speichern																				
AP 4: Excel-Anwendertool									⊙						⊙					
Task 4.1 Anforderungsprofil																				
Task 4.2 Toolentwicklung																				
Task 4.3 Testen und Validieren																				
AP 5: Fallstudien																		⊙		
Task 5.1 Fallstudie 1																				
Task 5.2 Fallstudie 2																				
AP 6: Dissemination														⊙						⊙
Task 6.1 Workshop mit Begleitgruppe																				
Task 6.1 Konferenzen und Publikationen																				
AP 7: Projektleitung und Berichterstattung												⊙								⊙
Task 7.1 Interne Projektkommunikation																				
Task 7.2 Berichterstattung																				

9.2 Status of work packages

Results from the first advisory board meeting on 4 June 2024:

Various relevant aspects for selection of thermal networks were discussed, including the distribution of network types, temperature levels and data sources for the costs of storage systems and network structure. Most of the participants in advisory board do not expect anergy grids to be widespread, which is why the project should focus on heat pump grids with centralised heat pumps. In addition, the necessity of modelling a night setback was discussed, although it still needs to be clarified whether this should be free or promoted/requested by the grid operator.

Storage variants to be compared in the project:

- No storage
- Centralised storage (realistic size e.g. in a city district)
- Decentralised non-cooperative storage cluster
- Decentralised intelligent storage swarm (bi-directional storage)

Status of the work packages:

- WP1 Selection of typical heating networks and demand profiles:
  The biomass heating network in Landiswil BE will be used as a typical reference network. This network will be used for all three analysed networks as an overall network respectively an individual line. The demand profiles are created by modelling buildings and generating domestic hot water profiles. Most of the work in WP1 has been completed.
- WP2 Boundary conditions (costs and CO_2 data):
  The determination of the cost basis for storage tanks and the thermal networks is in progress. The costs for storage facilities are provided by Jenny, the costs for pipelines by Verenum and the costs for district heating with wood taken from AHB Zurich publications. The KBOB database and, if necessary, the Ecoinvent database are used for the CO_2 data.
- WP3 System optimisations with optihood:
  The system optimisations are carried out with the optihood tool. One aim of the optimisation is to minimise the peak load. To facilitate modelling, a visualisation of the optimisation scenario was created in Excel. The biomass network has already been modelled.
- WP4 (Excel tool THENA):
  The first activities in WP4 have begun. The THENA Excel tool is being developed as part of WP4. The consortium held a half-day workshop at the end of October and discussed possible ways in which the SPF project results can be transferred to the THENA tool.