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HEAT STORAGE UNDERGROUND: A FEASIBILITY STUDY IN ZURICH'S URBAN CORE

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Abstract: This feasibility study investigates the potential of underground heat storage as a key component of sustainable energy infrastructure in Zurich's urban core. It focuses on leveraging subsurface spaces to support the expansion of district heating networks, with particular emphasis on seasonal thermal energy storage (STES). Central to the study is the proposed shift from a surface substation *(Kraftwerk Selnau)* to multifunctional underground sites that enable efficient and resilient thermal storage solutions. Key proposals include a centralised cavern concept in the University District and the adaptive reuse of existing structures such as the decommissioned former railway tunnel, *Letten Tunnel* for seasonal heat storage. The evaluation highlights how underground heat storage can enhance energy system resilience, reduce surface space use, and contribute significantly to Zurich's climate goals. The findings advocate for further exploration of cavern-based thermal energy storage systems as a future-proof strategy for urban energy supply.

Keywords: Seasonal Thermal Energy Storage, District heating networks, Heating and cooling, Planning of underground space, City planning

1. INTRODUCTION

1.1. District heating Zurich – Substation Selnau

The Selnau electricity substation, which has been out of use for its original purpose for nearly three decades, has since been reimagined as and evolved into a dynamic cultural and social hub. Today, it contributes to the vitality of the Selnau neighbourhood, serving as a landmark at the gateway between Selnaustrasse, Gessnerallee, and Zurich's main station. With its diverse offerings for the public, Selnau fosters community engagement, entrepreneurial innovation, and sustainable urban development (see Figure 1).

Figure 1. Kraftwerk Selnau in its current use as a business startup and cultural meeting hub (Pictures by Authors, 2023)

In parallel, the city of Zurich is pursuing the expansion of its district heating network *Coolcity*, considering the conversion of the former Selnau substation into a heat generation site for this network within the city center. To explore alternatives, the independent association IG SELNAU—comprising professionals from various disciplines in the built environment—commissioned a feasibility study to explore alternative solutions. This was carried out by SCAUT, Amberg Engineering and Rapp. The objective was to assess whether equivalent energy and urban development goals could be achieved by locating the planned energy center(s) in other underground sites within Zurich's central area, thereby preserving Selnau's current public and cultural use.

1.2. Underground space utilisation and urban development

Various aspects highlighted in this study play an important role from an urban development perspective. The evaluated underground concepts consider energy infrastructure for a district heating and cooling network in a dense urban setting. Whilst evaluating the possibilities of shifting the preferred location of the heat production plant, a strong focus on sustainability is incorporated into the final concepts. Our proposed solution integrates a large seasonal heat storage system into an already existing underground structure.

1.3. District heating network from an urban development perspective

A well-planned and efficiently operated district heating (and cooling) network makes a significant contribution to sustainable urban development by:

- Promoting energy efficiency and resource efficiency as well as energy independence.
- Improving quality of life in urban areas due to higher air quality and a reduction of the urban heat island effect.
- Increasing energy security and affordability for inhabitants.
- Strengthening the local economy.

It is therefore an important part of the multitude of efforts to pave the way forward in creating more sustainable cities.

1.4. Aqua thermal energy utilisation - water as a source for district energy systems

The use of lake water as a source for district energy systems is an increasingly established approach in cities aiming to reduce the environmental impact of heating and cooling. Aqua thermal energy harnesses the relatively stable temperatures of large water bodies—such as seas, lakes, or rivers—to provide both heating in winter and cooling in summer, typically through heat pumps and heat exchangers. This method allows for efficient, low-emission thermal energy production.

Several cities have already implemented seawater-based district heating and cooling systems on a significant scale, including Stockholm and Växjö in Sweden, Helsinki in Finland, Oslo in Norway, Vancouver in Canada, and Copenhagen in Denmark. These cities use aqua thermal energy as a cornerstone of their sustainable energy strategies, demonstrating its potential to reduce reliance on fossil fuels while supporting the decarbonization of urban heating and cooling networks. Beyond these examples, interest in aqua thermal energy is growing globally, with many municipalities exploring its integration into future-proof energy infrastructure.

To enhance the efficiency of aqua thermal systems, Seasonal Thermal Energy Storage (STES) is often used. STES allows excess heat collected during warmer months to be stored—typically in underground caverns, boreholes, or water tanks—and retrieved in colder periods when demand is higher. This enables a balanced, year-round supply of renewable thermal energy.

2. CLIMATE RESILIENCY OF CITIES

To ensure long-term sustainability, cities must adapt to the mounting challenges posed by climate change—among them, increasingly frequent heatwaves, storms, and flooding. These shifts not only stress urban infrastructure but also intensify energy demands for heating and cooling. At the same time, technological advancements and growing urban populations are reshaping how energy systems must operate: more flexibly, more efficiently, and with far lower emissions.

In this evolving context, energy resilience has become a critical aspect of urban resilience. It refers to the ability of heating and cooling systems to reliably operate during disruptions, adapt to changing conditions, and support cities in recovering quickly from both climate-related and human-made crises. Resilient energy infrastructure must be low-carbon, decentralized, and future-proof—especially in the face of volatile temperatures and increasing demand for indoor climate regulation.

Seasonal Thermal Energy Storage (STES) systems offer a promising solution. By capturing and storing thermal energy—such as heat from renewable sources or excess summer warmth—these systems allow cities to meet heating needs in winter and cooling needs in summer with minimal environmental impact. Underground spaces play a vital role here, enabling large-scale storage of thermal energy in subsurface aquifers, boreholes, or cavern systems, while freeing up valuable surface space for other uses.

Incorporating these systems into risk-informed urban planning is essential for preventing future disruptions and ensuring equitable access to thermal comfort. Inclusive planning, especially with a focus on vulnerable populations, not only reduces risk but also supports sustainable and just urban development.

As Brown (2014) argues, transitioning from traditional, single-purpose infrastructure to multifunctional, closed-loop systems—like those found in nature—can increase overall system resilience. In this "post-industrial paradigm," infrastructure must be versatile, interconnected, and synergistic. Thermal energy systems that combine surface and subsurface components are a prime example of this approach, integrating renewable energy, storage, and efficient distribution.

As Admiraal and Cornaro (2018) emphasize, harmonizing development above and below ground can offer strategic advantages in meeting urban resilience goals. With the majority of the global population projected to live in urban areas, using the "third dimension"—not just building upwards, but also downwards—will be crucial (SCAUT, 2019).

Our feasibility study embraces these principles by exploring how underground thermal energy storage and district heating and cooling infrastructure can contribute to a climate-resilient, sustainable future for Zurich’s inner city.

3. SUBSTATION SELNAU

The Selnau substation has served as a cultural, event, and meeting space for nearly 30 years, breathing new life into the Selnau district. Located at the gateway of the Selnaustrasse / Gessnerallee axis leading to Zurich’s main railway station, it attracts a wide and diverse audience with its variety of offerings. As a key destination in the area, the substation plays a significant role in Zurich's urban development, fostering sustainability, innovation, and the growth of a vibrant urban community.

Today, the substation hosts co-working spaces popular among startups and entrepreneurs—particularly those focused on sustainability—alongside a contemporary art museum, a café, and a restaurant.

Prof. Dr. David Kaufmann, head of the City and Landscape Network and urban development expert at ETH Zurich, shared the following with IG Selnau:

“Places like the Selnau power station, where many people come together without major commercial intent, are vital for successful and dynamic urban development. It is becoming increasingly difficult for such organisations and their non-commercial uses to secure space in central urban areas. The energy transition is adding pressure on these venues. The Selnau power station is a prime example. Cities need holistic strategies that drive the energy transition while also preserving the livability of the urban environment.”

- Impact Hub Zurich, which manages a portion of the building, reports the following activities in the substation:
- Annual visitors of between 100,000 and 120,000 for work, socialising, and events
- Over 100 cultural events per year, including exhibitions, music, and dance events
- Civic and policy engagement events
- Regular programmes focused on climate protection, sustainability, and innovation
- Daily use of facilities and catering services by freelancers and small businesses from the fields of business, culture, and science

The transformation of the Selnau substation from industrial infrastructure into a community-oriented space stands as a notable success for both the city of Zurich and the local Selnau neighbourhood. While this study does not quantify the social value or estimate the capitalised value of such public uses, these aspects merit further investigation in a dedicated analysis. What is clear is that transforming this lively community and business hub into an energy infrastructure would leave an unwanted void in this part of the city.

4. SWISS FEDERAL STRATEGY FOR UNDERGROUND SPACE UTILISATION

In the context of this study, it is highly relevant to reference the Swiss Underground Strategy, developed in 2022 by the Federal Geological Commission (EGK) on behalf of the Federal Department of Defence.

This strategy outlines a vision for harnessing the potential of the underground, aiming to strike a balance between utilisation and protection, while aligning with the responsibilities and priorities of both federal and cantonal authorities. A key goal is to improve the coordination of underground spatial planning.

As stated in the foreword to the strategy:

"The future of Switzerland lies largely underground. Climate adaptation, the energy transition, and the national energy supply are driving increased use of subsurface space."

It further notes:

"There are vast reserves of underground space that can support higher-density land use in response to urbanisation. [...] This positions Switzerland to play a leading role in international innovation."

Two specific objectives from the strategy are particularly relevant to this feasibility study:

(2) Sustainability: Responsible management of the subsurface contributes to Switzerland's sustainable development.

(5) Innovation: The innovation potential of underground resources is actively being leveraged.

The concepts and solutions explored in this feasibility study directly support these strategic goals. In contrast, the reference scenario—repurposing the centrally located Selnau substation for surface-level heat production—does not align well with the aims of the national strategy or does so only to a limited extent.

5. SUBSTATION SELNAU: PLANNED CONVERSION AND TECHNICAL DIFFICULTIES

Zurich's municipal energy provider, ewz, is planning to convert the Selnau substation into a district heating and cooling plant. This transformation would bring an end to the site's current public use, and existing tenants would be relocated outside the city centre. The facility is expected to provide a heating output of 55 MW and a cooling output of 36 MW.

The system will use water from Lake Zurich, extracted from a depth of around 25 metres, where the temperature remains approximately 5°C throughout the year. The thermal energy from the lake water will be transferred to a secondary circuit via heat exchangers located at a lakeside installation. From there, the energy is transported to the Selnau substation through a micro tunnel of about 850 metres in length and 3.6 metres in diameter.

The substation will house heat pumps, a small thermal buffer, and electrical systems. The building will be fully utilised from the start, leaving no space for future expansions or upgrades. To fit all necessary equipment, the demolition of the monumental Control Room (*Kommandoraum*), which is under historic preservation status (see Figure 2), will be required. Securing the necessary permissions for this will likely be time-consuming and complex.

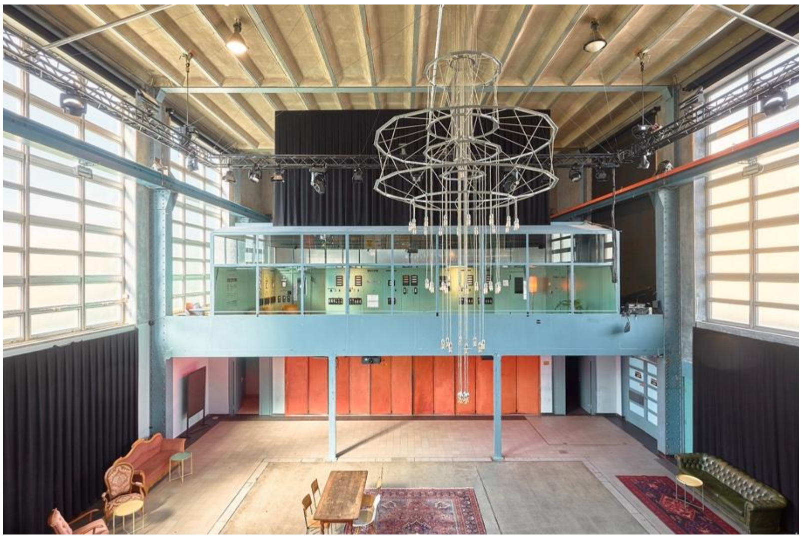

Figure 2. Monumental Control Room in Substation Selnau (IG Selnau, 2023)

The target excavation area for tunnel connection and pipeline integration lies underneath the substation's main hall and will need to be newly excavated. However, since no construction vehicles can enter the building, all excavation will have to be carried out through the windows. The site's location next to the Sihl River also presents geological and hydrological challenges, further complicating construction efforts. At this stage, permissions for construction have not yet been granted.

The planned plant's location at the western edge of the inner city's supply area is not ideal in terms of heat distribution. This feasibility study, therefore, explores alternatives that might place heat production facilities closer to key consumers and in locations that allow for simpler construction conditions in the underground.

While the use of lake water as an energy source is both sustainable and innovative, the Selnau site lacks the space for a seasonal or large-scale thermal storage system. As a result, any surplus heat, especially the heat produced from cooling, can only be stored temporarily before being discharged into the Limmat River, and eventually returned to the lake. On particularly cold winter days, when the heat pump capacity is insufficient, gas boilers will need to provide the additional required heat. A larger seasonal thermal storage system could help reduce this dependency on fossil fuels.

Furthermore, the pipeline and tunnel infrastructure being constructed for this project is designed for this specific use only. It will not support any future connections to other energy networks, which limits its adaptability and conflicts with the goal of multi-functional infrastructure in sustainable urban development.

As outlined above, both the site and system configuration of the Selnau facility have several drawbacks. An alternative approach could involve a distributed network, such as an anergy system. In this type of setup, the lake water is delivered at low temperature through a shared piping network directly to buildings. Individual heat pumps located in each building would then provide the necessary heating and cooling. This approach removes the need for a central plant like the one planned at Selnau. A similar model already exists in Geneva and is known as *Genilac*.

6. FEASIBILITY STUDY WITH EMPHASIS ON SEASONAL THERMAL ENERGY STORAGE

To meet the required heating and cooling demands for the Coolcity perimeter, various structurally different system configurations were evaluated. The primary goal was to identify feasible underground sites and assess their suitability for energy generation and long-term storage. Special attention was given to the potential integration of seasonal thermal energy storage (STES) to enhance energy efficiency and reduce environmental impact.

6.1. Overview of System Variants

Three spatial configurations for the heating plant were assessed:

- A decentralised solution using shafts at multiple locations within the Coolcity perimeter
- A combined centralised–decentralised approach, involving a reduced facility at the Selnau substation and an additional nearby site
- A fully centralised solution located just outside the Coolcity perimeter

6.2. Underground Location Types

Three underground construction types were considered:

- Conversion of basements in existing public or private buildings for district heating purposes
- Cut-and-cover underfloor systems, which allow continued use of the surface space above
- Mined underground systems, where heating infrastructure is built below the surface in a cavern system without disrupting above-ground activity

The latter is particularly well-suited for large-scale heat storage integration.

6.3. Site Selection Process

- Step 1: Identification of 17 potential sites in Zurich where underground space is available and construction is viable. Five of these were located outside the Coolcity perimeter to potentially cover a larger area. See sites depicted with their considered type of construction (Figure 3): shaft, cavern or re-used underground space.
- Step 2: Geological evaluation based on existing data. Most sites within the perimeter are situated in loose rock formations, limiting construction methods. The Lindenhof hill was the only site within the perimeter with more favourable conditions (30 meters of moraine). Promising locations outside the perimeter include the Sihlberg and the University district, the latter offering access to molasse layers and existing underground infrastructure.
- Step 3: Hydrogeological assessment. Most locations within the perimeter had unfavourable conditions, except Lindenhof. However, due to archaeological protection regulations, the top 10 meters of Lindenhof cannot be used. Its lower layers, which intersect groundwater, pose additional challenges, limiting the possible cavern size.

- Step 4: Site-specific evaluation of constructability and thermal storage potential.

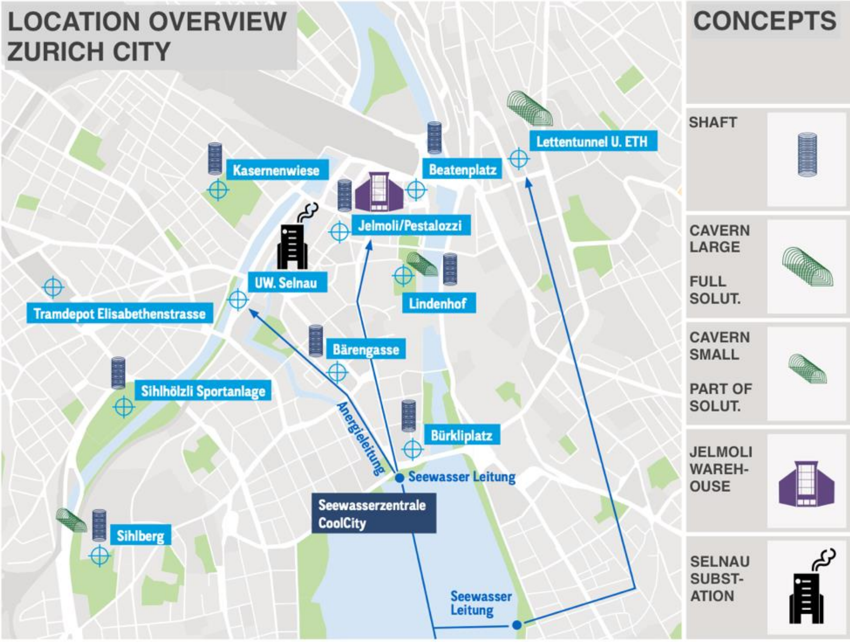

Figure 3. Evaluated locations and their assessed solutions in Zurich city (SCAUT, 2023)

6.4. Evaluation of Concepts

6.4.1. Shaft Network Concept

This concept involved the construction of seven shafts throughout the Coolcity perimeter. Each shaft would have a 13-meter outer diameter (10 meters internal), allowing minimal environmental disruption. However, due to the area's geology and hydrogeology, construction costs would be relatively high. Splitting a heating plant across seven units increases system complexity and operational inefficiency.

Importantly, this approach does not allow for the integration of large-scale seasonal heat storage, which would reduce long-term fossil fuel use. Based on cost, complexity, and lack of scalable storage, the shaft solution was deemed the least favourable.

6.4.2. ETH Cavern Concept

Located in the University district just outside the Coolcity perimeter, this concept combines existing and new underground structures (see Figure 4):

- A former parking garage (Parkhaus Zentral)
- A decommissioned 2 km-long railway tunnel (Letten Tunnel)

- A newly constructed underground cavern (see Figure 4, right)

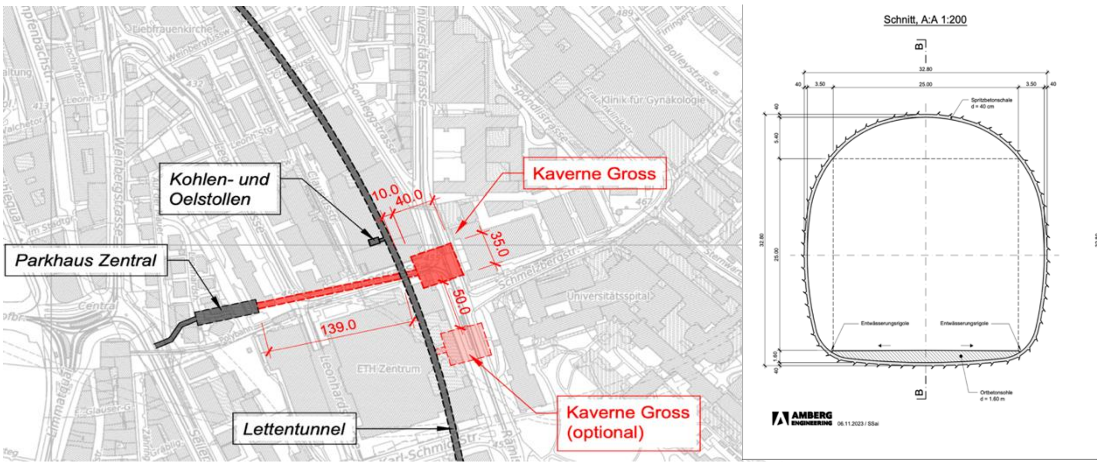

Figure 4. ETH Cavern concept (left), Cavern design (right) (Amberg Engineering, 2023)

The Letten Tunnel offers a unique opportunity for seasonal heat storage, with a total volume of 50,000 cubic meters. Using it as a seasonal thermal storage system allows excess summer heat to be stored and reused during winter, eliminating the need for fossil-fuel peak load systems, as currently planned for Coolcity. This could reduce CO_2 emissions by approximately 3,000 tonnes annually.

Further benefits include:

- Proximity to a planned lake water energy extraction point, enabling synergies with other heating systems
- Reuse of existing infrastructure, lowering costs and environmental impact
- Space for future expansion, with the option to build additional caverns
- Closer location to major heat consumers compared to the current Selnau site
- The ETH concept offers the best combination of geological, hydrogeological, spatial, and technological conditions for integrated energy generation and seasonal thermal energy storage (STES).
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6.4.3. Combined Selnau–Lindenhof Concept

This solution splits the heating plant between the existing Selnau substation (for the western perimeter) and a new, smaller cavern at Lindenhof (for the eastern part). While this improves network coverage, it has several drawbacks:

- Higher overall construction and operation costs
- Continued reliance on suboptimal hydrogeological conditions at Selnau
- Limited excavation depth at Lindenhof reduces its suitability for heat storage
- The potential for seasonal thermal storage is minimal in this setup, making it less attractive from a long-term sustainability perspective.

7. PROPOSED SOLUTION

Each concept has strengths and drawbacks. The shaft-based solution is flexible but relatively expensive and unsuitable for STES. The combined Selnau–Lindenhof option improves coverage but introduces cost inefficiencies and fails to eliminate fossil fuel reliance effectively. The ETH cavern concept (see Figure 5) offers the best long-term value, due to:

- Integration of a large-scale seasonal thermal energy storage system
- Reuse of existing underground infrastructure
- High geological and hydrogeological suitability
- Proximity to planned energy extraction points and major heat users
- Potential for system expansion through additional caverns

Given its sustainability, technical feasibility, and lower environmental impact, further development of the ETH concept is strongly recommended.

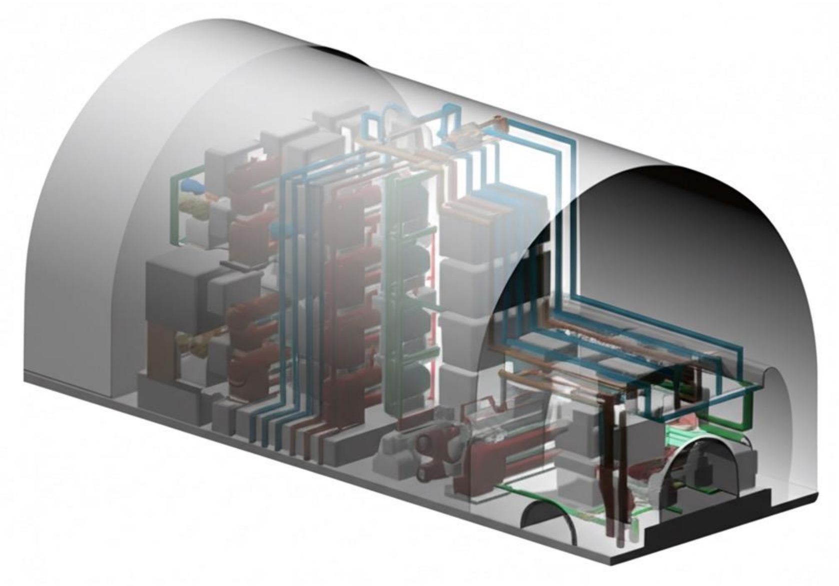

Figure 5. Proposed solution: Heating and cooling plant in a cavern

8. CONCLUSION

This feasibility study demonstrates that underground heat storage has strong potential to contribute to Zurich's or any city's sustainable energy future. While the planned conversion of the Selnau substation faces significant technical and spatial challenges, alternative underground concepts—particularly the ETH cavern approach—offer more resilient, scalable, and climate-aligned solutions. By reusing existing infrastructure such as the Letten Tunnel and integrating large-scale Seasonal Thermal Energy Storage, Zurich can reduce its reliance on fossil fuels, lower CO_2 emissions, and strengthen urban energy resilience. Advancing the cavern-based concept would not only align with the Swiss Underground Strategy but also safeguard valuable cultural and social spaces at Selnau, making it the most future-proof option for the city's district heating network.

9. REFERENCES

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