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Low-temperature Heating and Cooling Grids Based on Shallow Geothermal Methods for Urban Areas

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ABSTRACT

Low temperature heating and cooling (LTHC) grids are innovative approaches to meet the heating and cooling demand especially in urban areas. In October 2018 the authors started the interdisciplinary applied research project "Smart Anergy Quarter Baden" (SANBA), with the aim of developing a LTHC grid for the former military camp "Martinek-Kaserne" in the City of Baden south of Vienna, which was abandoned in 2014 and for which there are plans to develop a new urban mixed-use quarter. The main challenge for this project is the condition of the buildings which date back to the 1930s and which are protected by cultural heritage. The need for refurbishment of the buildings is given regardless of their future use. The refurbishment of the buildings that they are suitable for a low-temperature heating and cooling distribution system is a new aspect for the owner, the Austrian Federal Ministry of Defence. Key elements for the LTHC grid are the use of industrial low-temperature waste heat from processes in the neighbouring NÖM dairy plant as well as the development of refurbishment and conversion concepts for the protected buildings.

1. INTRODUCTION

Low temperature heating and cooling (LTHC) grids are innovative approaches to meet the heating and cooling demand especially in urban areas. District heating systems face a transition of decreasing grid temperatures alongside the transition towards an increase in renewable energy use up to 100 % (Lund et al., 2014; Lund et al., 2017). LTHC grids were installed first in Switzerland around 10 years ago. In Austria, some research projects have dealt with the feasibility of those grids and in Vienna, there are two small LTHC grids in operation (Biermayr, et al., 2013; Götzl et al., 2017). The topic of LTHC grids gains increasing attention particularly in urban areas in Austria, due to (I) the increasingly lower temperature demand of heating distribution systems in new buildings which often have a high building standard (passive house or similar); (II) energy efficiency measures in old buildings (thermal insulation, new windows etc.); and (III) the trend to decentralised heating and cooling grids with an increased share of renewables, supporting local or national climate and energy goals. The number of so-called local energy communities, especially in urban and sub-urban areas, where high-temperature district heating is not available or where the building and usage structure allows for low-temperature heating and cooling, is expected to increase substantially over the next years.

In general, the knowledge of the main components of LTHC grids is well developed. The actual challenge is not the design of the single components but rather the hydraulic and thermal interaction of all components with its high degrees of freedom. Standard procedures for the technical design of common district heating networks and geothermal installations are therefore not appropriate. For that reason, a fully dynamic simulation tool with coupled thermo-hydraulic processes is important for dimensioning the components and their interaction with the grid. In comparison to common district heating networks the flow direction is bidirectional. Hence, heat can be carried to and from the consumer, depending on the season and heating/cooling demand. The geothermal energy storage must balance the residuum of the actual energy demand of all users and should be designed with balanced annual heat load and discharge. Finally, a complex network with the interaction of many users and different load functions and constraints have to be considered in the system design. Additionally, the possible change of users or power loads must be taken into account and concepts for reliability have to be elaborated. In addition to the seasonal geothermal storage also technical thermal storages may play an important role, when a short time balance of heating and cooling is required or to optimize the heat pump operation time.

Furthermore, it is of advantage to use photovoltaic (PV) systems for the operation of the heat pumps and their impact will therefore be under investigation in this project.

LTHC grids are, technically speaking, networks of pipes, distributing water with temperatures in the range of 8 and 22 °C at most times (min. 2 and max. 30 °C) between individual buildings and/or groups of buildings. The water can be used for free cooling as well as cooling or heating with the help of heat pumps. Usually, the networks are connected to seasonal storage units for thermal energy (Figure 1) (Zach, 2016; Zach et al., 2016).

LTHC grids have the following main characteristics (Figure 1) (Zach et al., 2016):

- Low grid temperatures (4 - 30 °C) for supplying heat pumps (heating and cooling) as well as provision of free cooling capability, if the temperature level is suitable.
- Include seasonal underground storage of thermal energy, with balanced annual heat load and discharge.
- Implementation of available local low exergy heat sources (e.g.: waste heat, solar heat, geothermal resources, waste water heat).
- Low carbon emission and low environmental footprint.

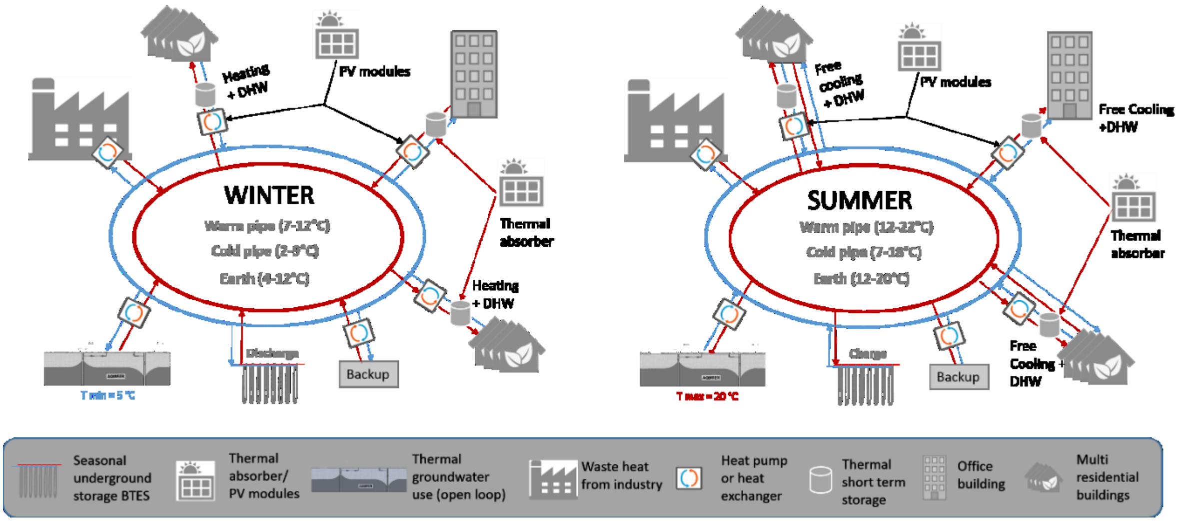

Figure 1: Illustration of the general concept of a low-temperature heating and cooling grid, its components, and the operating conditions in winter (left) and in summer (right).

2. PROJECT SMART ANERGY QUARTER BADEN (SANBA)

In October 2018 the authors started an interdisciplinary applied research project, with the aim of developing a LTHC grid for the former military camp "Martinek-Kaserne" in the City of Baden south of Vienna, for which there are plans to develop a new urban mixed-use quarter. Key elements are the use of industrial low-temperature waste heat from processes in the neighbouring NÖM dairy plant as well as the development of refurbishment and conversion concepts for the protected buildings.

2.1 Investigation area former military camp "Martinek-Kaserne" in Baden south of Vienna

The former military camp "Martinek-Kaserne" was constructed by architect Leo Splett of the construction management of the German Luftwaffe during the war years 1938 to 1943 as antiaircraft defence base. After the Second World War, the camp was used by the Soviet Army and then by the Austrian Military until 2014, when the Military Camp was abandoned. The property owner is the Austrian Armed Forces with the Austrian Federal Ministry of Defence as superordinate institution.

Figure 2: Satellite view of the "Martinek Kaserne" and the NÖM dairy plant (Google Earth)

The vast property with an area of 40 hectares with buildings protected by cultural heritage has been subject of several development plans over the years. Plans to sell the property to an investor were unsuccessful up to now, since the conditions of the buildings and the sheer size of the project has proven a challenge too big even for the most ambitious investors. Over the last years the main stakeholders, i.e. the Federal Ministry of Defence as property owner, the City of Baden, the Federal Monument Protection Agency, and the neighbouring municipality Sooß, which owns a small part of the “Martinek-Kaserne” property, have discussed several options for the future use of the area. Some areas of the former camp can potentially be developed with new buildings, whereas these developments have to be elaborated with the main stakeholders, mentioned before.

One of the biggest challenges of the project is the status of some of the buildings of the “Martinek-Kaserne”. Since the abandonment in 2014, the condition of the buildings deteriorates very rapidly (Figure 3). In a meeting with the Federal Monument Protection Agency in April 2018, the representative of the Agency made a statement which summarizes the need for refurbishment measures concerning the buildings: *“One year of abandonment of the buildings has the same implications for the buildings as ten years of use”.* This statement emphasizes the need for action, because every year of non-use deteriorates the buildings at an exorbitant rate. Independent of the future use of the buildings, there has to be a concept for refurbishment soon.

Buildings under cultural protection are subject to certain limitations in terms of thermal renovation and energy efficiency. From the provisions of monument preservation external insulation is usually not permitted, as they affect the appearance of the building massively. The focus is on measures that can increase energy efficiency without endangering their appearance or substance. Despite energy efficiency measures, buildings under protection usually have a higher heat load. Higher heat loads are provided by high flow temperatures of the heat distribution system. A LTHC grid works with low supply temperatures and usually requires customers to get accustomed to low supply temperatures to maximize the performance of the heat pumps.

2.2 Scenarios for a future use of the “Martinek-Kaserne” and resulting research questions

Figure 3: Pictures of the interior of the buildings and the outside area. The central staff building with the main entrance and the round tower is well-preserved. The upper two pictures show the dining hall and the main meeting room in the round tower. In some pictures, the poor condition of the buildings – partially due to damage by water - even after only four years of abandonment and signs of vandalism can be seen.

Over the past years after the abandonment, the “Martinek-Kaserne” has been subject to many development plans. The need for refurbishment of the buildings is given regardless of their future use. The refurbishment of the buildings that they are suitable for a low-temperature heating and cooling distribution system is a new aspect for the owner, the Federal Ministry of Defence. The Ministry itself carried out or ordered studies for a possible future use of the buildings. Three possible scenarios for planning and simulation of the LTHC grid for the “Martinek-Kaserne” will be developed.

- Use of only the existing building stock with protected buildings (“Mini”)
- Use of the existing buildings stock + 50 % of free area with new buildings (“Midi”)

- Use of the existing building stock + 80 % of free area with new buildings ("Maxi")

The subsequent work for the design of the LTHC grid will be carried out in close coordination with the stakeholders. The design and simulation of the grid will be independent of the future use, whereas a future use of the "Martinek-Kaserne" again merely as a military camp is excluded after talks with the stakeholders. The user and therefore load profiles of the buildings are assumed as mixed, with housing, commercial and office buildings, education etc., whereas we can work with preliminary studies of architects and developers as a guideline for the development of the scenarios.

3. DESIGN OF THE LTHC GRID

In a first step, all essential data from the site will be gathered, whereas the available data can be classified as follows:

a. *Geoscientific data:* (hydro-)geological data, e.g. maps, data of boreholes, existing water rights; construction of test borehole, enhanced thermal response test (eTRT) measurements, soil and water examinations, geoelectric measurements;
b. *Technical data:* Possible components in the LTHC grid, technical and energetic specifications and boundary condition;
c. *Building data:* Assessment of the existing building stock, load profiles etc.;
d. *Economic data:* Definition of essential cost components, price research etc.

ad a.: After the geoscientific data collection and the measurements at the borehole, a hydrogeological model will be established out, which will feed into a process model based on the software FEFLOW™ to assess the thermal interaction of thee subsurface (solid soil and possible groundwater layers) with the seasonal heat storage.

ad b.: Following the three scenarios, the distinct energetic boundary conditions will be developed for each scenario. Furthermore, the energy system of the NÖM dairy plant will be analysed to determine the energy potentials for the LTHC grid.

For the simulation of the LTHC grid new and communicating simulation tools will be developed to cope with the complex situation of the area, consisting of different heat sources, protected and potential new buildings, different temperature levels and times of energy demand, different uses of the buildings, etc. The tool will comprise

(I) the heat recovery from the wastewater, cooling units and compressed air of the neighbouring NÖM dairy plant,
(II) integration of locally available renewable energy sources,
(III) energy storage aspects,
(IV) the special challenge of different building standards of the old protected buildings vs. newly built buildings with different usages (living, commercial, education), and therefore different supply temperatures and demand characteristics, and
(V) moderate cooling via Free Cooling.

ad c.: The existing building stock will be assessed with regard to the renovation needs and the thermal requirement for refurbishment, in accordance with the monument protection standards. Subsequently, the free areas will be assessed for potential new buildings and usage, in order to generate realistic load profiles. For each scenario, the HVAC systems will be designed, including the energy transfer to the LTHC grid and the energy distribution within the buildings.

ad d.: On the basis of the available cost data, a method for a comprehensive economic assessment of the LTHC grid, considering environmental costs and benefits will be developed. The calculations support the assessment of the competitiveness of LTHC grids with industrial waste heat and geothermal heat supply compared to fossil-fuel based grids and district heating.

4. FIRST RESULTS

4.1 Setting up a hydrogeological subsurface model of the site

Estimating the resources for generating and storing heat based on shallow geothermal methods (open- as well as closed loop systems) requires the knowledge of the subsurface conditions up to the maximum depth of planned installations. In SANBA, the maximum depth of shallow geothermal installations is limited to 150 meter. For the general evaluation of our site at the former Martinek military camp in Baden, we aim at estimating the following subsurface characteristics:

- Lithological build-up for creating a thermal property model (bulk thermal conductivities and bulk heat capacities);
- Hydrogeological set-up in order to (1) delimitate the zone of partial saturation, identifying groundwater zones suitable for the application of open loop systems and (3) evaluate the thermal storability of the site;
- Any limitations for the use of shallow geothermal systems given by anthropogenic contamination and sensitive groundwater bodies (e.g. overpressure, karstic or thermal water bearing) for the delimitation of maximum drilling depths.

The hydrogeological model established in SANBA refers to literature- and archive data (lithological borehole profiles, hydrogeological cross sections and existing water permits in the closer vicinity of the site) as well as on two geoelectric (DC) resistivity profiles, which have been measured in the framework of SANBA. The campaign was executed between April and June 2019 and focused on resolving the resistivity in depths up to 150 meters.

In a first step, all information available from literature and archives were compiled to a geological cross section, which is shown in Figure 4. In general, the subsurface at depths up to 150 meters below the military camp is dominated by fine grained, partly sandy marls and clay dominated marls of the Vienna Basin. Groundwater bodies are only expected in the uppermost 10 to 20 meters and might not allow the use of open loop systems for generating heat due to moderate hydraulic conditions. At the base of the marly layers we expect conglomerates and breccia, which might be connected to a regional thermal water system in the Vienna Basin. These layers, which might appear in depths between 170 and 250 meters must not be drilled during the installation process of closed loop systems to avoid any damage of the aquifer through leakage or contamination by drilling mud.

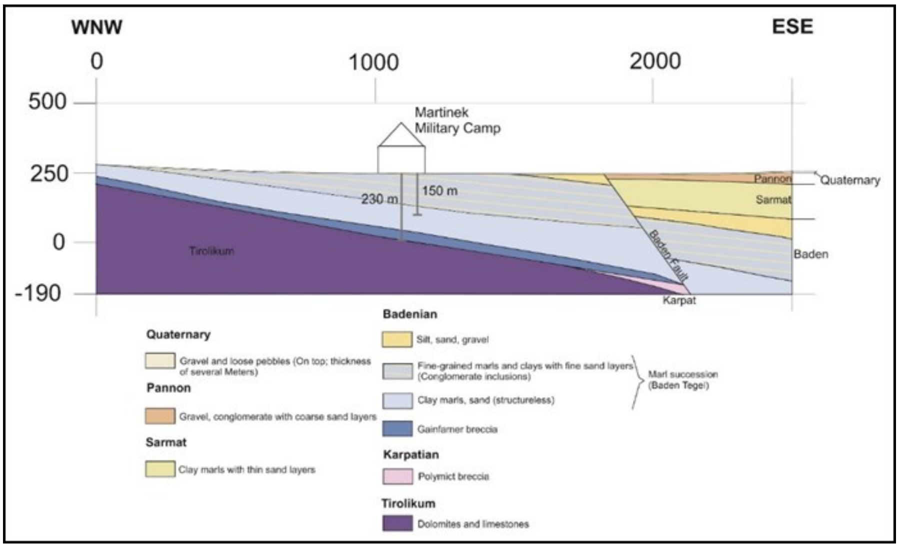

Figure 4: Geological cross section at the Martinek former military camp in Baden.

The compiled geological cross section was afterwards evaluated by the results of the DC resistivity campaign in late spring 2019. In addition to the data from literature and archives, the geoelectric campaign revealed a zone of increasing resistivities in depths between 80 and 100 meters, which may indicate interbedded sand or conglomerate layers, which dip in Northern direction (see also Figure 5). These layers might bear an additional aquifer, which could be either used for generating heat or might reduce the thermal storability of the site.

In a next step, an exploration well with a maximum depth of 150 meters will be drilled at the site. This well will be used to calibrate the DC resistivity measurement and to adapt the geological cross section for expanding it into a full 3D model. We are also planning to transfer the DC resistivity model into a thermal conductivity model along the measured profiles. In case aquifers are detected in the deeper part of the subsurface, pumping tests will be applied in order to evaluate the hydraulic potential and the possible reduction of the thermal storage efficiency due to advective heat transport.

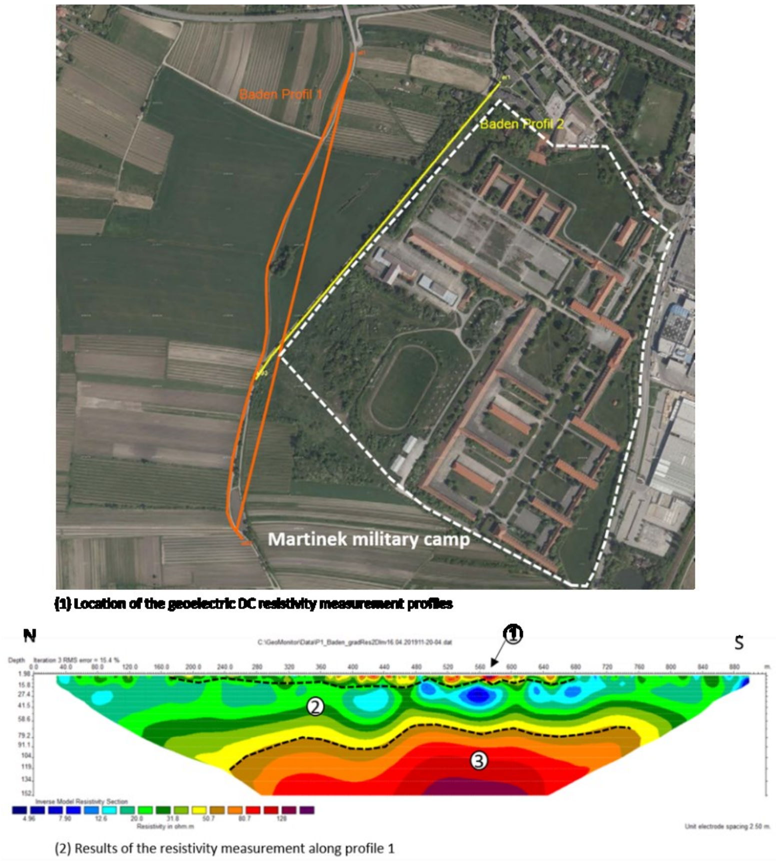

Figure 5: Location and results of the DC resistivity measurement at the Martinek military camp in Baden. The results indicate three main zones: (1) shallow gravel-based aquifer in the uppermost 10 meters; (2) clay and marl dominated zone and (3) a zone of increasing resistivity indicating higher sand contents or interbedded conglomerates.

4.2 Technical system design for the LTHC grid

First design strategies for the technical design of the components of the LTHC grid have been made. The future use of the buildings – different for each scenario – was classified into eight categories, as can be seen in Table 1. These categories are expected to have different heat load curves and therefore must be treated separately. For instance, there are archives in scenario MINI and it is determined, that heating is only necessary for frost control. Most of the categories of future use apply to both (redeveloped) housing stock and newly built houses.

Table 1: The future use of the buildings, classified into eight categories

	Redeveloped housing stock	Newly built house
Residential	×	×
Office	×	×
Education (school, campus)	×	×
Archive	×	
Gastronomy, event	×	×
Shops	×	×
Hotel		×
Supermarket		×

Heating in housing stock for all categories is carried out in the form of floor heating with a supply temperature of 35°C and additional radiators for load peaks with a supply temperature of 63 °C. The higher building quality of the newly built houses makes it possible to heat only with surface heating (supply temperature of 35 °C).

Due to low domestic hot water demand in office and educational buildings the hot water supply in housing stock as well as newly built houses is decentralized with electrical hot water generation. For the buildings of housing stock with categories except office and educational buildings a centralized domestic hot water supply is chosen. Part of this system is a hot water storage tank with a supply temperature of 63°C construed for 12 hours and an additional electric heating element for reaching higher temperatures of 70 °C to handle the risk of legionella development. For the newly built houses a decentralized domestic hot water supply with fresh water stations is intended that provide supply temperatures of 50°C without the necessity of a second storage tank.

A first attempt for the realization of the LTHC thermal network has been made for the scenarios MINI and MAXI in respect to the number and size of prosumers, geographical circumstances (such as cellars and existing heat stations) and the design of the network itself. A ring network topology is used for these scenarios, which is common for ground coupled heat pump systems. A smaller ring size is preferable due to the better dynamic flexibility despite a higher overall sum of pipe length. The pipe lengths are summarized in Table 2. In Figure 6 the network of the LTHC grid can be seen for scenario MINI and MAXI.

Table 2: Pipe lengths in the scenarios MINI and MAXI

	MINI	MAXI
Length of ring network in m	1646	1826
Length of supply lines in m	711	1072
Sum in m	2357	2898

4.3 Waste heat potentials from the waste water of neighbouring NÖM dairy plant

In order to determine the waste heat and energy efficiency potentials of a plant and to analyse the energy system, the data of the existing energy flows must be determined in a first step. In the case of the dairy investigated here, these are waste heats from compressed air compressors, from cooling units and from the waste heat of the waste water from the various cleaning processes.

The latter occurs during the cleaning process of the plant. The chemical cleaning process is carried out by CIP (Cleaning in Place). The sequence of a CIP cleaning process is divided into several steps such as pre-rinsing, alkaline cleaning, rinsing, acid cleaning, rinsing and disinfection. This is a crucial energy consumer of a dairy. The thermal energy for cleaning is provided by steam.

The temperature curves of the wastewater flows from the CIP process were analysed over a period of more than 1.5 years, with the following Figure 7 showing one month as an example.

Figure 6: Network of the LTHC grid for scenario MINI and MAXI.

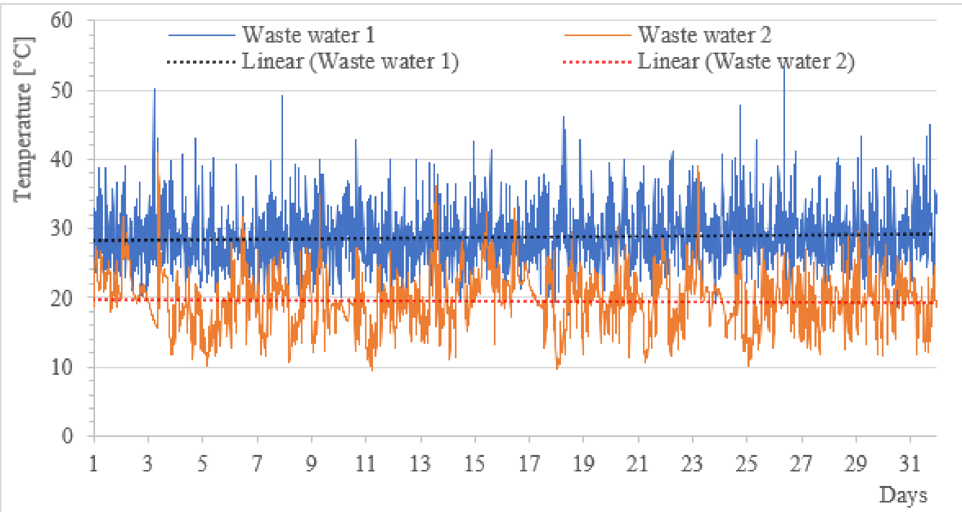

Figure 7: Temperature curve of the two waste water streams from the CIP processes over a period of one month. The dotted lines show the linear trend of the two temperature curves.

As seen in Figure 7, the temperatures are relatively constant, which is a consequence of the numerous daily rinsing processes. This is of great importance for the use of waste heat. It can also be seen that the temperature curve of waste water stream 1 is at a significantly higher level, about 12 K higher than the waste water temperature of waste water stream 2. In addition, the volume flow rates of both wastewater flows were evaluated over a period of 7 months. It was found out that waste water flow rate 1 is about five times the size of waste water flow rate 2. It is also of importance here that the volume flows are relatively constant due to the numerous daily rinsing processes.

Of particular interest here is the achievable waste heat recovery. With a moderately assumed cooling temperature of 20 °C, an average of 900 kW of heat output can be recovered from the period investigated according to first calculations. If the cooling temperature is lower, it is possible to recover more power, but this is determined by the temperatures of the low-temperature heating and cooling grid.

4.4 Economic System Assessment

The task opens up numerous research questions with business economics relevance. Empirical experiences are available almost exclusively from the area of conventional local heating networks. Simple, common but nevertheless meaningful and unerring approaches address the thermal power and thermal annual work density along the network paths. Proven limits for the economic operation of heat networks are a power density greater than (0.5) -1.0 kW_{th} / m network length of a 2-pipe network and a density of work greater than 1.5 MWh_{th} / (m * a). The relation between power density and work density depends on the type of use of the building and can cover a wide range. Thus, permanently inhabited residential buildings have a balanced ratio of thermal power and thermal annual work needs, while e.g. hotels with pronounced but short seasons have high power, but low work requirements.

Therefore, for an economical operation of district heating networks, on the one hand, there must be suitable demand structures and, on the other hand, suitable tariff models must be used.

The heat supply which the SANBA project deals with has a very inhomogeneous building structure. On the one hand, these are historic, monument protected buildings with a low degree of compaction and an anticipated residential or office use which can only be thermally renovated to a minor extent. On the other hand, new buildings are planned for mixed use which should at least have a low energy standard. Moreover, the new buildings cannot exceed a certain degree of compaction, since the appearance of the ensemble must not be disturbed by the new buildings which are bigger than the old buildings. For the economical operation of a district heating network, these are major challenges. In addition to numerous techno-economic optimization problems of plant dimensioning, the research project ultimately raises the question what the use of industrial waste heat may cost. This not only refers to the business model of the heat-supplying commercial enterprise, but it also refers to the costs of the required technical development such as the pipe path to the commercial enterprise, a possibly large-volume low-temperature heat exchanger or the pumps and their operation.

Despite the specific challenges that the given building structures bring with them, so far numerous approaches with great potential for optimization have been found:

- Due to the size of the overall system, economies of scale can be used in many areas. These occur in different system components such as heat pump units, technical heat storage, geothermal heat storage, pumps, piping, etc.
- In the planning, modular, standardized aggregates of components are sought, which minimize the costs, e.g. standardized heating centres for building.
- The land use restrictions that arise through the preservation of monuments, in turn, allow a cheap realization of pipe routes for the LTHC heat grid.
- Due to the planned geothermal heat storage, the energy service of the building cooling can be offered. This possibly brings a double benefit (revenues from building cooling and free revitalization or charge of the geothermal storage).

Ultimately, the appearance of the overall system economics will also depend on which optional system a comparison is made with. In any case, the claim of the project lies in a largely greenhouse gas-neutral heat and cold supply of a city expansion area with special requirements by historical, protected buildings.

5. CONCLUSIONS

The project results will support the stakeholders in the decision, whether the concept of an LTHC grid at the area of the "Martinek-Kaserne" is technically and economically feasible and whether this concept should be pursued further. The project is still ongoing until February 2021 and further results will be presented at the World Geothermal Congress 2020.

The project's results will be an important first step contributing to the wider implementation of LTHC grids in Austria. It will allow for the screening of sites as well as for the planning of grid designs. The consortium is aiming to support potential developers with the realisation of the LTHC grid at the "Martinek-Kaserne" military camp in the near future.

Furthermore, a positive demonstration of the feasibility of LTHC grids for protected buildings and/or buildings which are subject to refurbishment, can lead to further application of these concepts at other military camps. The Federal Ministry of Defence is one of the biggest land owners in Austria and owns many other military camps in Austria, for which LTHC grids could be an interesting option for a future sustainable energy supply.

6. ACKNOWLEDGEMENTS

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