# Buried Twin Pipe Model Validation for System Simulations of Ice Storage Tanks in 5GDHC networks

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**Abstract**

As cooling becomes more and more important for the building sector in central Europe, low temperature 5th Generation District Heating and Cooling (5GDHC) networks are of increasing importance. Different heat sources for such networks exhibit different limitations. While waste heat is limited through its origin, the capacity of ground and lake water is limited by their temperature levels in winter, while abundant heat is available in summer times. Therefore, the integration of seasonal thermal storages can be of great benefit. One option is the implementation of ice storages as long-term load shifting elements. Moreover, peak demands during both heating and cooling periods demand for oversizing the heat/cold supply. Here ice storages can play a different role by providing additional short-term capacity for heating and cooling on the coldest and hottest days respectively. In this paper, we present 5GDHC network configurations in which ice storages can be operated in a useful manner. Furthermore, we analyze the temperature levels and differences in a 5GDHC network over a year as a basis for tuning the parameters of a buried double pipe model typically employed in such networks.

*Keywords: Thermal Networks, 5GDHC, Ice Storage Tanks, Solar-Ice Systems*

## 1. Introduction

Thermal networks running on a low temperature level are becoming more and more important all over Europe (Caputo et al., 2021). The advantage of such networks is that waste heat at low temperature levels (e.g., from sewage plants or data centers) or environmental heat from various sources (e.g., lake or ground water) can be used. Additionally, low temperature networks, also called 5GDHC (5th Generation District Heating and Cooling networks), have the potential to provide cooling in summer. About 40 % of potential sources of 5GDHC networks are, however, limited (Sres and Nussbaumer, 2014) and therefore may be short during the heating period. Storages play an important role in this context for shifting the available heat on a seasonal basis as well as on shorter timescales. Ice storages are used for heating applications as seasonal storages in solar-ice based heating systems in single and multi-family buildings (Carbonell at al., 2021). In district heating networks with anti-freeze heat transfer fluids, ice storage tanks could replace geothermal probes. While borehole fields need a temperature level of 25 °C to 30 °C for regeneration (Ruesch and Haller, 2017), ice storages can be regenerated at any temperature above 0 °C. Smaller ice storages may be used for load shifting on shorter timescales like weeks as additional heat sources for covering the coldest days. Moreover, ice storages could be used for short term cooling load shifting helping the electric grid to be more flexible, thus providing a double function for heating and cooling peak load shifting. In this paper we present results of analyzing monitoring data of a 5GDHC over year, which in turn are used to validate a network pipe model implemented in TRNSYS.

## 2. Network configurations compatible with ice storages

To bring the temperature level of a 5GDHC network up to a range at which the heat can be used in applications such as room heating or domestic hot water, distributed heat pumps at the user sites are employed. Besides the lower operating temperatures, the main feature distinguishing 5GDHC networks from earlier generations is the bidirectional energy flow (Caputo et al., 2021). The low temperature levels allow that different users of the same network can be in different operation modes (heating or cooling). Within such a bidirectional energy flow network,


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only certain configurations can be combined with an ice storage in a useful manner.

The three configurations we identified as useful, are shown in **Fig. 1**. In case a) the ice storage is located at the site of the central heat source. Here the ice storage can be regarded as an alternative to a borehole field. Case b) depicts a specific version of case a), in which the main heat source is represented by solar thermal collectors and/or air heat exchangers. Unlike case a), where the ice storages can be an add-on to an existing (waste) heat source, the ice storage is an integral part of the heat source in case b). Only the combination with an ice storage enables the usage of solar thermal collectors and/or air heat exchangers. Finally, in case c) one or more smaller decentralized ice storages are used at the user sites to shift loads on shorter timescales on the network end of the heat pump system. Here they can be seen as potential replacements for sensible storages.

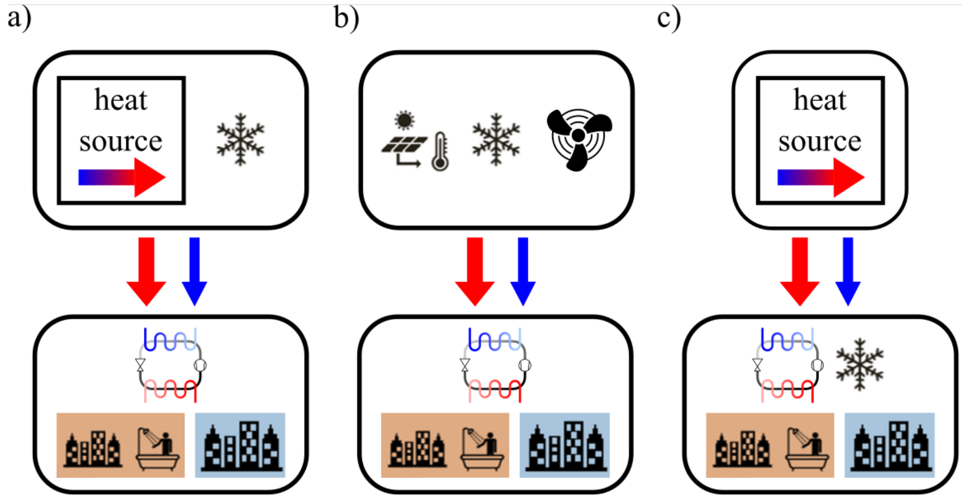


**Fig. 1: Network configurations considered for implementation of ice storage tanks. a): Centralized ice storage at the location of the main (or one of the main) heat source(s). b): Combination of storage combined with air source heat exchanger and/or solar thermal collectors as the main heat source of a network. c): Decentralized ice storages (e.g., at consumer substations with cooling needs) for shorter term load shifting.**

## 3. Analysis of existing 5GDHC network

5GDHC networks usually feature uninsulated buried double pipes. Because of the lack of insulation these pipes interact significantly with both the ground and with each other. To gain insight in the behavior of a network based on such pipes, monitoring data from a 5GDHC network in Zurich (Switzerland) were analyzed. In its final stage of extension this network is supposed to cover the heating demands of around 5500 inhabitants distributed over around 2200 dwellings in the year 2050. In 2020, which is the year analyzed in the following, the network included two data centers with a combined nominal heating demand of 80’000 MWh/a, two ground probe fields with a combined 332 probes of 250 m length and six energy substations with a total installed power of 7.3 MW. The network nominally provided 35’000 MWh heat for space heating and domestic hot water. The energy reference area serviced was 185’000 $m^2$. The network length is 1’500 m and the heat transfer fluid used is untreated water.

The monthly energy balance of this network for the year 2020 is presented in **Fig. 2**. Network components that add heat to the system (sources) are on the positive and components that take heat from the system (sinks) are on the negative side. All values exact for those labelled “pipes heat exchange” were extracted from monitoring sensors. The “pipes heat exchange” is simply the difference between the sinks and the sources values, ensuring that a balance is achieved. We assume that these imbalances are entirely due to thermal losses and gains that happen in the network pipes and hence named them accordingly. It can be clearly seen that the heat losses through the pipes are higher for the warmer months from April until September as compared to the remaining colder ones. Since the ground is still relatively warm in November from summer, there are slight pipe heat gains for the network during this month. The ground probe fields act as heat sinks from April to October and as heat sources for the remaining months.

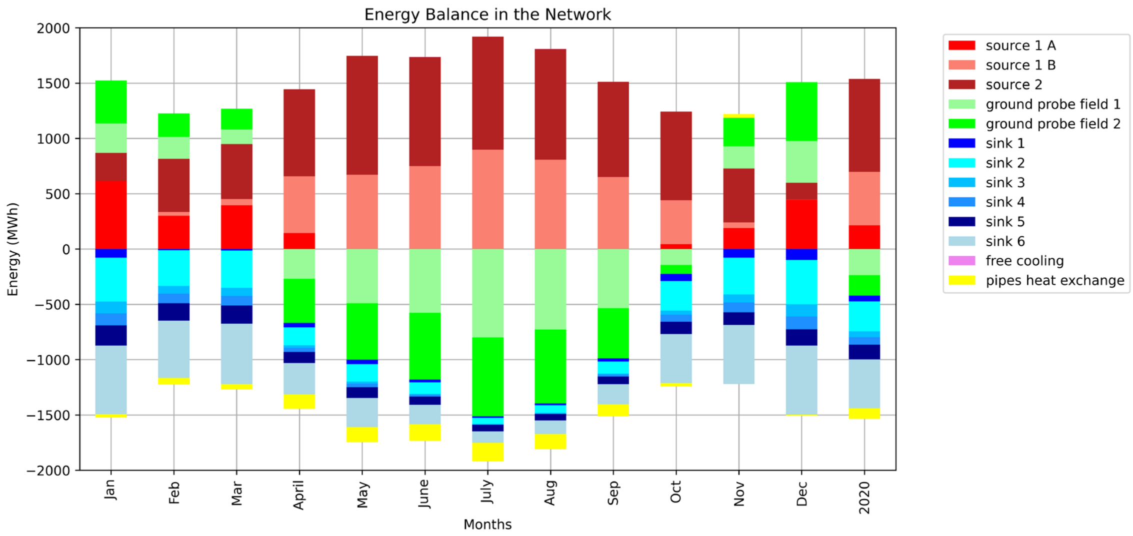


**Fig. 2: Energy balance of the network for the year 2020 with all sinks and sources and the ground probe fields. Pipe heat exchange (yellow parts of the bars) on the negative side (sink-side) means overall losses, on the positive side (source-side) means overall gains of the network. The "2020" bar represents annual values which are divided by a factor of 10 for being in a similar range as the monthly bars.**

There is a 580 m long section of the network between the two substations of Source1 and Groundsource2 with no further substations in between. This piece of double pipe should allow for a deeper analysis of pipe losses and gains. The respective temperatures over the year 2020 are shown in **Fig.** *3*. The temperatures of the warm (solid line) and the cold (dashed line) pipes are shown at Source1 (blue) and Groundsource2 (orange) in **Fig.** *3 a)*. The temperature level outside the heating period (April – October) is up to 27 °C in the warm pipe, while it stays just below 25 °C in the cold one. This is above the ground temperature even in warm summer months and explains the pipe losses. From November to March the temperature level of the network is around 15 °C in the warm and around 11 °C in the cold pipe. The drop in temperature occurring in November marks the start of the heating season.

**Fig.** *3 b)* shows the temperature differences for the warm (red line) and the cold (blue line) between the two substations Source1 and Groundsource2. These temperature differences directly reflect the heat losses and gains for the two pipes over the examined section. The temperature difference is taken between the downstream and the upstream point in each pipe. This means that the difference is formed in an inverse fashion between the warm and the cold pipe, since the flow directions are opposite to one another. Consequently, heat losses are reflected by positive and heat gains by negative values in the temperature difference. It should be noted that for the year 2020 there was a predominance of cooling over heating demand leading to relatively high network temperature and hence to relatively large losses. These will be reduced when more heat sinks are connected to the network, as planned.


**Fig. 3: a): Absolute temperature of the network for substation Source1 and Groundsource2 (GS2). The warm/cold pipes are represented by a solid/dashed lines respectively. b): Difference of network temperature between substation Source1 and GS2 for the warm pipe in red and network temperature difference between GS2 and Source1 for the cold pipe in blue. Between substations Source1 and GS2 there is 580 m of buried, uninsulated double pipe. Note that the spike in October constitutes an outlier caused by a data logging issue.**

## 4. Validation of double pipe model and simulation framework

The project Ice-Grid will include simulations of 5GDHC networks featuring ice storages. These will be done with the open-source simulation framework pytrnsys (SPF-OST, 2019) and TRNSYS as core engine. The pipes of the networks will be modelled through an extension of Type 951 from the TESS library (TRNSYS, 2019) representing a "buried twin pipe". Here the extension consists of adapting the model such that it supports changing flow directions in both pipes, which is not possible with the original model.

While most parameters of the pipes, like their diameter for example, are simply known from planning data, the thermal conductivities of both the pipe material and the soil are determined through fitting them to the monitoring data presented in the previous section. It should be noted that the temperature sensors from the data in **Fig. 3** have a measurement uncertainty of 0.1 K. Therefore, the temperature loss of the cold pipe of about 0.1 K lies within the uncertainty range and even the higher temperature losses of the warm pipe of about 0.4 K are close to the uncertainty range.

In the buried double pipe model two identical pipes are symmetrically placed in a common casing with a fill material embedded by soil. The flow direction of the pipes is defined by the sign of the mass flow rate which is given as inputs to the model. Only conductive heat transfers between the pipe and the filling material and soil is considered. Thermal resistance between the pipes and between each pipe and the surrounding soil are calculated. Around the casing a finite difference model of soil conduction is employed to calculate heat accumulation and dissipation. While the volume excavated to lay the pipes and fill with filling material has a rectangular cross section in the real system, the geometry of the model is concentric around the symmetry axis of the double pipe.

Note that the radius around the symmetry axis for which interaction with soil can be considered is limited to the burying depth of the pipes. These circumstances are illustrated by **Fig. 4**.

All other geometric parameters are fixed to the physical values of the installed network. The pipes have an inner diameter of 42 cm, the distance between the centers of the pipes is around 75 cm and the pipe depth is taken to be 2 m below the surface, which is about the average of pipe depth in the relevant part of the system.

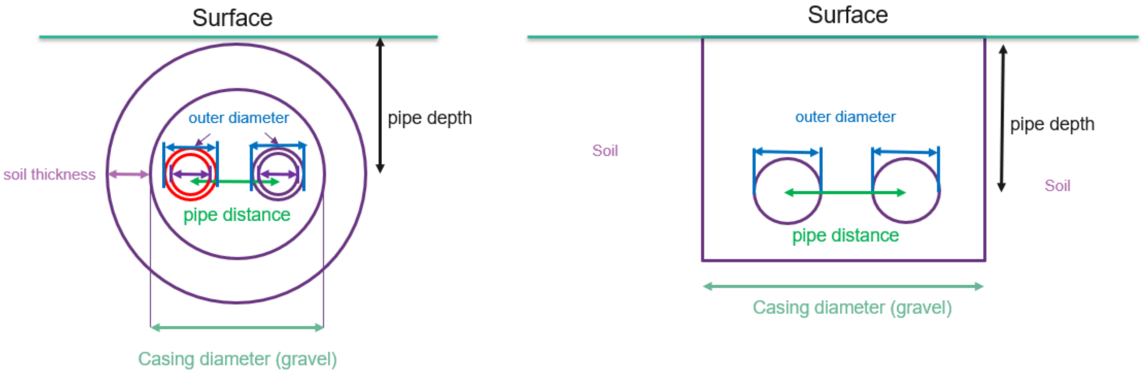


**Fig. 4: Comparison of model geometry (left) and geometry in a real network (right).**

In a first step the effect of the meshing resolution was analyzed by varying the number of control volumes. The accuracy did not increase when going beyond the default settings of 5 radial soil nodes and 4 circumferential soil nodes. So, the numbers of nodes were kept at these values. In a next step the effect of thermal properties (conductivity and capacity) of the fill material and surrounding soil were tested. Mainly changes in the thermal conductivity of gravel and soil have been analyzed. For the pipe itself a typical heat conductivity value for plastic pipes was selected.

Thermal conductivities of ground and filling material vary over the year depending on the water saturation of the ground. Water saturated loam or gravel have much higher thermal conductivities than their dry counterparts. A summary of thermal ground properties can be found in Santa et al. (2017). In the model used here the ground properties are assumed to be constant over time.

To calibrate the thermal conductivities of the soil around and the gravel between the pipes assumed in the model, a simple simulation was set up. This simulation includes a section of double pipe representing the 580 m long section between Source1 and Groundsource2 analyzed above. For this test simulation the inlet temperatures and mass flow rates of the two individual pipes were simply read from the measured data and the respective outlet temperatures were returned. The thermal conductivities were then varied to minimize the difference between annual losses measured in this part of the network and the annual losses determined through the simulation. Exploring different parameter variations, the best match between measurement data and model was found at a thermal conductivity of 3 W/(mK) for the filling material (gravel) and 2.35 W/(mK) for the soil. At these values the annual difference in thermal losses between the simulation and measured values is less than 5%.

The respective outlet temperatures of the pipes for two selected parts of the year are shown in **Fig. 5**. The model outputs (lines) match the measurement data (dots) well. The temporal sections in spring (April) and fall (September) were selected because they exhibit strong temperature dynamics.

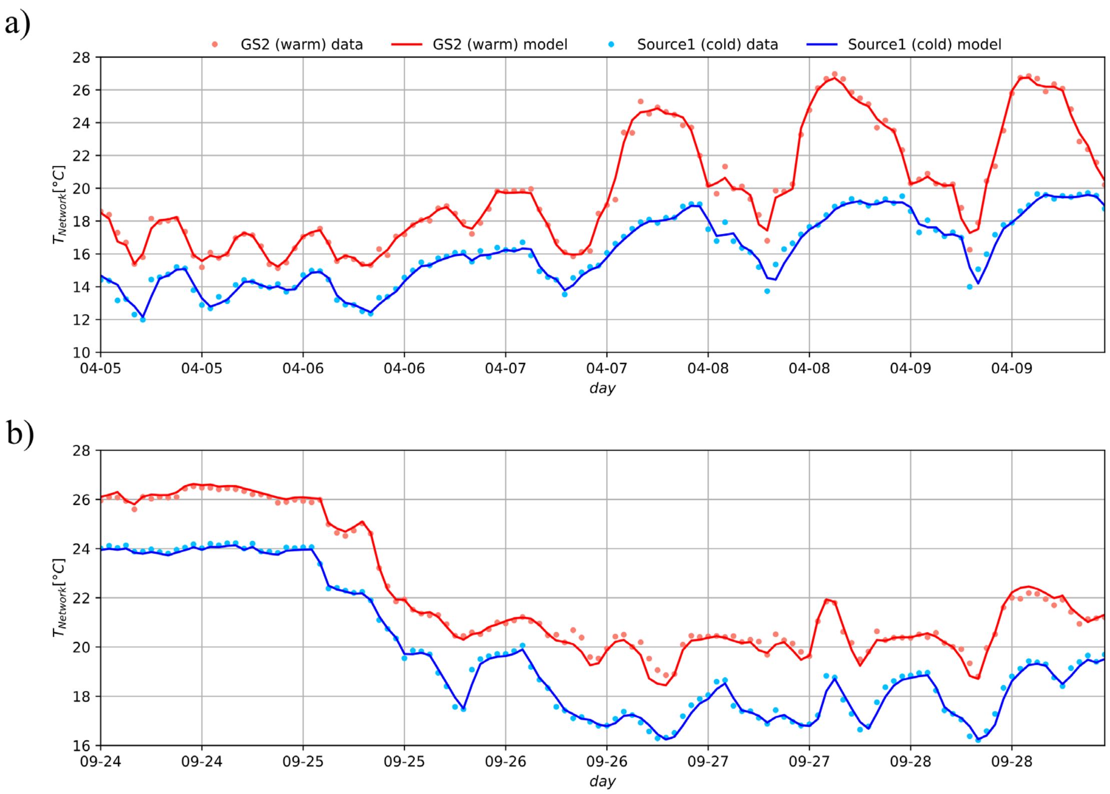


**Fig. 5: Temperatures at Source1 and GS2 for warm and cold pipes. The measurement data is represented through dots and the model output by lines. Two temporal sections of the analyzed year with a pronounced dynamics were selected: April 5th to 9th in a) and September 24th to 28th in b).**

The open-source TRNSYS framework pytrnsys, that will be used for the simulation in the current project also features a graphic user interface (GUI) that facilitates setting up the hydraulic systems to be simulated with TRNSYS. Pytrnsys is being currently extended from building HVAC systems to feature district heating networks within two national Swiss projects. This extension includes the possibility to connect district heating network components with double pipe connection by drag and drop, which can be automatically exported into a specific TRNSYS type handling hydraulic connections. An example of the GUI with a generic district heating network is shown in **Fig. 6**.

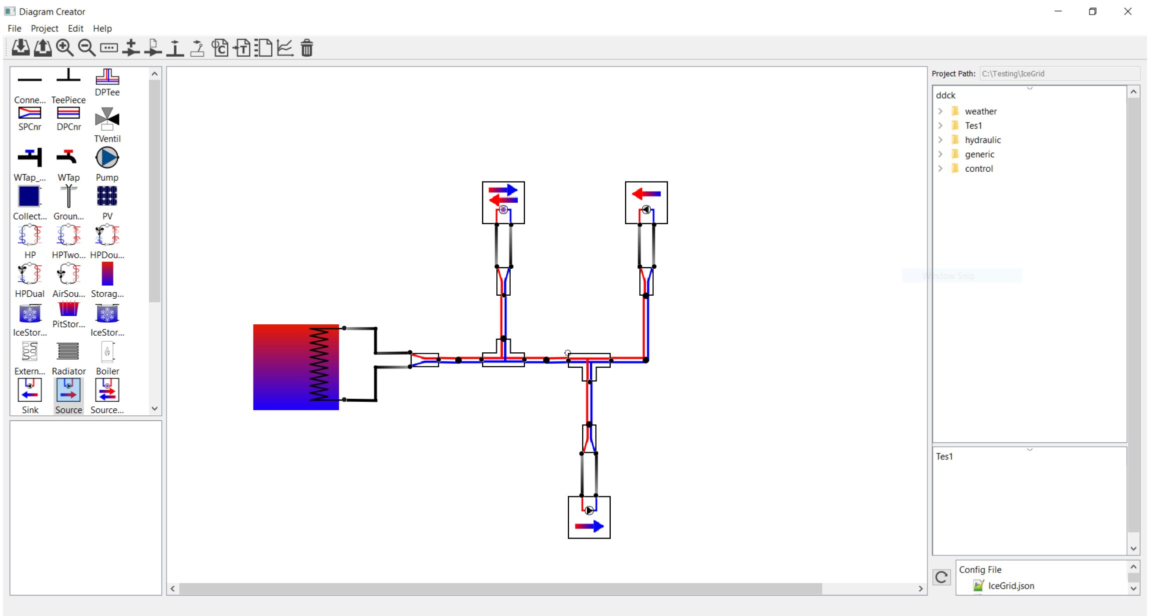


*Fig. 6: Screenshot of the graphical user interface of pytrnsys while setting up a hydraulic scheme featuring a district heating network.*

## 5. Conclusion

The qualitative behavior of the data measured on a double pipe section of a 5GDHC network is completely in line with the expectations. The beginning and end of the heating season are clearly visible as changes in the temperature level of the network. The relatively high heat losses can be attributed to a rather high temperature level overall, rooted in the abundance of heat sources as compared to sinks during the year monitored. The assumption that these losses will decrease significantly when the temperature level is decreased due to the addition of heat sinks, is well justified by the behavior of the system for the month of November. There the sudden temperature drop due to the onset of the heating season correlates even with heat gains in the network.

Employing the buried twin pipe model developed as an extension of TRNSYS TESS library type 951 during the current projects a good agreement between model output and measured data can be achieved when tuning the thermal conductivities of the filling material between the pipes and the surrounding soil while fixing the remaining model parameters to their nominal values.

Together with the identification of relevant network configurations and the extension of the TRNSYS framework pytrnsys to district network simulations, the validated buried twin pipe model forms a solid base to explore the usage of ice storages 5GDHC network through system simulations.

## 6. Acknowledgments

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