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Decarbonizing Heating and Cooling Systems via a 5GDHC Network Powered by Shallow Geothermal Energy: A Case Study from the Catalan Pyrenees in the FlexGeo Project

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ABSTRACT

Decarbonizing the heating and cooling sectors is a key challenge in Europe's fight against climate change. Aging and inefficient systems present opportunities for innovative solutions like fifth-generation heating and cooling district (5GDHC) networks, which integrate renewable energy sources for maximum efficiency and minimal greenhouse gas (GHG) emissions. In Vielha, a town in the Catalan Pyrenees (NE Spain), many public and private buildings require modernization of their outdated, fossil fuel-dependent heating and cooling systems. To tackle this, the local government of the Aran Valley (CGA) and the municipality are promoting solutions based on local and renewable energy. A key initiative is the "Vielha Smart Multi-RES micro DHC grid," aimed at decarbonizing public buildings through a 5GDHC that combines shallow geothermal energy with solar photovoltaic energy.

As part of this initiative, the CGA in collaboration with the Geological Survey of Catalonia (ICGC) conducted a fieldwork campaign mainly during 2024 to characterize the hydrogeological properties of the ground. This campaign involved new drilling instrumented boreholes with sensors and fiber-optic up to 100 meters deep, coring, and performing DTRT tests to further develop a 3D flow and heat transport model to design the borehole heat exchangers (BHE) field array following a Borehole Thermal Energy Storage (BTES) concept. The geological model integrates reinterpreted data from two previous geophysical campaigns (2012 and 2020), which focused on determining the Quaternary infill geometry of the valley and the depth to bedrock, using the H/V spectral ratio technique.

Additionally, under the co-funded Horizon Europe R&D project FlexGeo 2024-2028 (*Pathing the Way for Flexible Geothermal Energy Systems with Reversible ORC Systems, Advanced Control and Novel System Designs*), led by the Technical University of Munich, ICGC address the dynamic energy modelling of the Vielha case study in OpenModelica. This model, utilizing the Modelica Buildings Library (v.10.0.0) and Modelica Standard Library (v.4.0.0), conceptualizes a 1-pipe 5GDHC network where a centralized borefield serves as the balancing unit. The modelled thermal loads include those from a sports center, an ice rink, a swimming pool and two educational buildings. By examining current demands and building characteristics, various prospective scenarios have been analyzed to generate an optimal and flexible solution, enhancing energy efficiency on the supply side.

1. INTRODUCTION

Vielha is located in the north-westernmost part of Catalonia (Spain), in the heart of the Pyrenees, at the bottom of a glacial valley, carved by the Garonne River (*Val d'Aran*). The town sits at an altitude of 980 m a.s.l. and has a population of around 3,700.

Figure 1. Location (left) and view (right) of Vielha Town. The arrow marks the project location.

It is surrounded by steep, forest-covered mountains reaching elevations of up to ~3,000 m. Although Vielha appears to benefit from abundant local renewable resources – such as hydropower and biomass – it still relies almost entirely on the national electrical grid and daily deliveries of fossil fuels (including propane, butane, and gas oil transported by truck along a long, winding road) to meet its energy needs.

In recent years, however, the *Conselh Generau d'Aran* (CGA, the autonomous regional government) has initiated the sustainable exploitation of local biomass resources. More recently, the "Vielha Smart Multi-RES micro DHC grid" initiative was launched in collaboration with the Catalan Geological Survey (ICGC). This project aims to promote a paradigm shift in the thermal and electrical energy supply of this remote region in the Catalan Pyrenees by integrating shallow geothermal energy (SGE) and photovoltaic solar energy (PVSE) into a novel district heating and cooling (DHC) network, with the dual goal of decarbonizing the energy supply and improving both affordability and security.

A selected group of existing public buildings has been identified as initial candidates for transitioning from outdated gasoil and gas boiler systems to closed-loop SGE-based systems – specifically, borehole heat exchangers (BHEs) coupled with ground source heat pumps (GSHPs) – hybridized with PVSE panels and connected to a common thermal grid. Most of these buildings have heating-dominated demand profiles, which could lead to a long-term decrease in ground temperature, the extent of which largely depends on the dynamics of heat exchange with the subsurface.

However, the hydrogeological context presents several uncertainties that must be addressed beforehand to determine the most suitable configuration. The valley where Vielha is located is of glacial origin, with a substrate composed of fractured Paleozoic rocks overlain by Quaternary alluvial sediments of variable thickness (ranging from 5 to 20 m) (see Figure 2). While groundwater flow is expected, assessing its direction, velocity, and the effective thickness of the aquifer is crucial to deciding whether a borefield thermal energy storage (BTES), heat restoration, or heat exchange system is best suited to the buildings' needs.

The research approach presented in this work is structured into three main components (see Figure 3). The first focuses on identifying and collecting real thermal demand data from the buildings to prospect on project design. The second involves fieldwork and data processing aimed at characterizing the hydrogeological context, which will be used to further create a 3D transport model of the groundwater flow and the heat (not attained in the present work). The third addresses the dynamic modelling of a district heating and cooling (DHC) network proposal. These three components are closely interconnected, forming an iterative process designed to generate sufficient knowledge to support decision-making on the most suitable configuration for a hypothetical DHC network in Vielha.

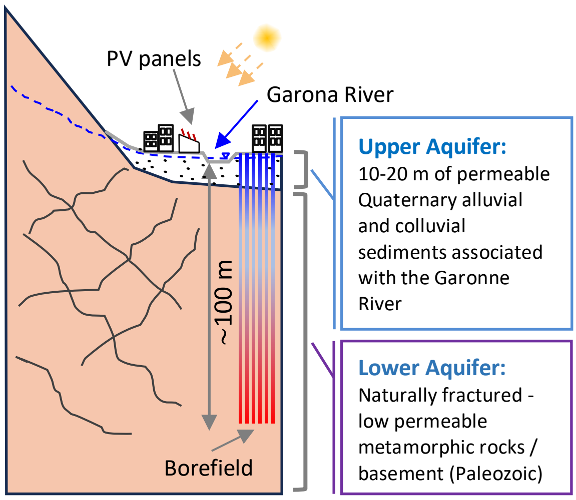

Figure 2. Schematic "cross-section" of the site, showing a simplified illustration of the subsurface structure and the prospective BHE depth (~ 100 m).

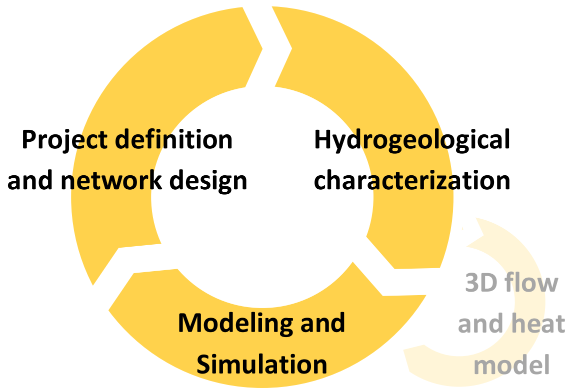

Figure 3. Simplified workflow of the present study, structured into three main components and following an iterative research approach. An additional branch involving 3D groundwater flow and heat transport modelling will be addressed in a dedicated future publication.

The case study presented in this work is partly developed within the framework of the European research project FlexGeo (*Pathing the Way for Flexible Geothermal Energy Systems with Reversible ORC Systems, Advanced Control and Novel System Designs*), funded under the Horizon Europe program (2024 – 2028). FlexGeo aims to develop and demonstrate innovative geothermal system designs that enhance both performance and flexibility. The project also addresses advanced control strategies for District Heating and Cooling (DHC) networks, the integration of Underground Thermal Energy Storage (UTES), and the optimization of system configurations for future geothermal deployment across Europe. The overarching ambition is to accelerate the market uptake of sustainable, replicable geothermal technologies and to support the EU's net-zero greenhouse gas emissions target.

In the Vielha case study, the challenge of implementing flexible, geothermal-based solutions is addressed through dynamic modelling and simulation under OpenModelica environment. Modelica is a powerful language specifically designed for simulating the dynamic behavior of complex physical systems. A key outcome of IBPSA Project 1 (formerly IEA-DHC Annex 60) (Wetter et al., 2015) has been the development of several open-source Modelica libraries that have become widely adopted by the building energy modelling community (Abugabbara et al., 2022; Hinkelman et al., 2022; Mans et al., 2022). Among them, the Modelica Buildings Library (MBL), maintained by Lawrence Berkeley National Laboratory (California, US), stands out for including detailed models of water-to-water heat pumps and other HVAC components (LBNL, 2024).

The proposed initial configuration follows a hybrid fifth-generation district heating and cooling (5GDHC) network with a 1-pipe layout, in which a BTES system acts as the balancing unit (BU), capable of supplying, absorbing, or storing heat depending on the thermal dynamics of the connected buildings.

2. MATERIALS AND METHODS

2.1 Building demand data

As a first proposal for the project, a set of 4 buildings were chosen as the first candidates to be connected to the future grid (see Figure 4).

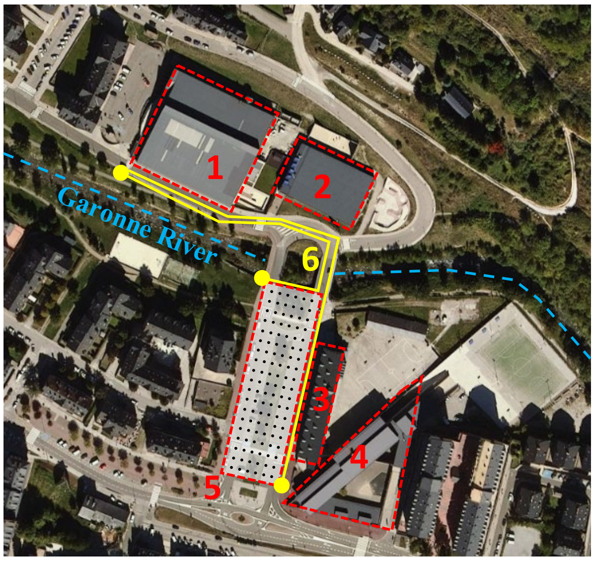

Figure 4. Aerial view of the buildings potentially involved in the future 5GDHC network: 1) Ice Rink and swimming pool; 2) Sports Centre; 3) Secondary School; 4) Primary School; 5) Proposed location for the BHEs; 6) Proposed layout for the distribution pipes.

These are an Ice rink complex ("Building 1", named *Palai de Gèu*), which includes under the same roof an ice-skating platform next to a swimming pool and a gymnasium, a sports center ("Building 2", named *Palai d'Espòrts*) with a multisport court, a secondary school building ("Building 3", named *Institut d'Aran*) and a primary school building ("Building 4", named *Escòla Publica Garona*). The current heating, domestic hot water (DHW), and cooling generation systems were identified through on-site inspections. Nevertheless, obtaining accurate demand data proved challenging, as none of the buildings are equipped with thermal energy meters, and electrical consumption is not disaggregated to isolate usage from space conditioning systems. For this reason, the "actual" thermal demands were inferred based on annual fuel consumption and the nominal capacity of the installed systems (see Table 1). The installed equipment is listed below:

- Building 1: 2 x 550 kW_t air-to-brine chillers (ice rink) and 2 x 400 kW_t gas-oil-fired boilers (swimming pool and gymnasium).
- Building 2: 2 x 350 kW_t propane-fired boilers
- Building 3: 3 x 130 kW_t propane-fired boilers
- Building 4: 1 x 400 kW_t propane-fired boiler

Table 1. Identified total installed heating and cooling capacity in Buildings 1-4, and inferred values of heating + DHW and cooling demands.

		Building			
		1	2	3	4
Heating and DHW	Installed Capacity [kW_t]	800	700	390	400
	Inferred Demand [MWh_t]	1351	266	285	411
Cooling	Installed Capacity [kW_t]	1100	-	-	-
	Inferred Demand [MWh_t]	1786	-	-	-

The area available for BHE implementation covers approximately 5,700 m^2 (polygon number 5 shown in Figure 4), where up to 200 BHEs could be installed with 5 m spacing. An important technical aspect regarding the pipe layout (see lines marked as "6" in Figure 4) is that the group of buildings is divided by the Garonne River. As a result, the distribution pipes can only be routed beneath the bridge that connects Buildings 1 and 2 with Buildings 3 and 4 and the borefield.

2.2 Hydrogeological site characterization

The fieldwork campaign involved the drilling of four boreholes: two for geothermal exchange analysis (labeled as "SXGV01" and "SXGV03" in Figure 5) and two for geological investigation (labeled as "SXGV02" and "SXGV04" in Figure 5).

The two geothermal boreholes (100 m deep, ~ 25 m apart) were equipped with single U-tube polyethylene probes embedded in geothermal grout (λ_{grout} = 1.7 W/mK) and instrumented with thermistors at 10 m intervals. Each was fitted with a composite fiber optic cable enabling both Distributed Temperature Sensing (DTS) and Active Distributed Thermal Response Testing (ADTRT), as it contains both a sensing fiber and a copper heating element. While conventional Thermal Response Tests (TRTs) were performed to estimate bulk thermal properties, DTS and ADTRT allowed for spatially resolved estimations of thermal conductivity (λ_g) and of groundwater flow velocity (v_{gw}). All boreholes were connected to telemetry systems for real-time monitoring, and part of the dataset is publicly available via the Catalan Geological Survey (ICGC) web portal (ICGC, 2024).

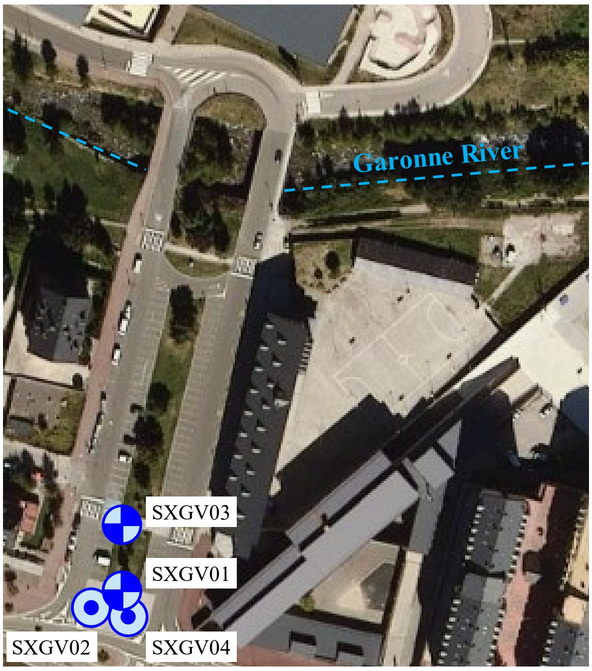

Figure 5. Exact location of the two open boreholes (SXGV02 and SXGV04) for geological investigation, and the two closed boreholes (SXGV01 and SXGV03) equipped for geothermal exchange analysis.

Geological investigation included a 21 m borehole targeting Quaternary deposits, and a 102 m borehole into fractured Paleozoic bedrock. Both were equipped with piezometric pipes for monitoring groundwater levels and temperatures, and a mini-pumping test was conducted in the deeper borehole to assess hydraulic properties.

TRTs were performed on both geothermal boreholes using a Geocube GC500 apparatus (Precision Geothermal LLC, USA), each lasting ~ 48 h, with a constant specific heat rate injection of 47.8 W/m. Data was also interpreted using a Distributed Thermal Response Test (DTRT) approach. An additional ADTRT was conducted in April 2025 using a Silixa Ultima DTS and Heat Pulse Control System (Silixa Ltd., UK), injecting 7.67 W·m^{-1} for 72 h. Temperatures were recorded every 0.25 m at 25 s intervals and analyzed using the MATLAB-based ADTS Toolbox (Simon and Bour, 2023), which enabled the estimation of thermal conductivity and inferred groundwater flow velocity based on the Moving Instantaneous Line Source (MILS) model (Carslaw and Jaeger, 1959; Simon et al., 2021; Sutton et al., 2003; Zubair and Chaudhry, 1996).

The mini-pumping test in the bedrock aquifer consisted of 7 h of pumping followed by 8 h of recovery, and was interpreted using Theis and Jacob methods (Banks, 2012).

2.3 District heating and cooling network modelling

The model of the Vielha use-case was developed using the Modelica Standard Library (MSL) (version 4.0.0) and the MBL (version 10.0.0) in the OpenModelica environment (OMEdit version 1.24.0). The approach consists of a main model representing a 5GDHC network, where a set of different sub-models were generated for the buildings (treated as "prosumer stations" in the model), the pipes and the control logic. It presents hierarchical architecture based on several layers of inheritance between the different sub-models involved.

For the simulations, hourly-resolved demand profiles were artificially generated using nPro software tool (Wirtz, 2023). These profiles are based on the inferred nominal heating and cooling nominal demands (D_H^{nom}, D_C^{nom}, respectively) detailed in Table 2. The selected supply temperatures (T_H^{supply} and T_C^{supply}) reflect the characteristics of the existing building distribution systems, while also remaining within the typical operating limits of GSHPs. The nominal capacity of the GSHP models is estimated under nominal conditions (P_H^{nom}) corresponding to an evaporator temperature of 10 ºC and a condenser temperature of 45ºC. (see Table 2), applying an oversizing security margin of 20 %. In the case of Building 1, two separate prosumer station entities were modelled: one for the heating and DHW demand of the swimming pool and gymnasium (Prosumer station 1a), and another for the cooling system of the ice rink (Prosumer station 1b). One additional prosumer station is also modelled corresponding to a hypothetical 5th building (invented heating and DHW demand profile), although there is not yet a firm candidate in the project.

Preliminary borefield sizing was performed using the G.POT method (Casasso and Sethi, 2016), incorporating the effective thermal conductivity λ_g and thermal diffusivity (α_g) values obtained in this study (see Results section). An initial estimate suggests a borefield consisting of 100 to 130 BHEs, spaced approximately 5 m apart. A long-term minimum temperature limit (T^{lim}) of – 2 °C was set for the heat-carrying fluid (expected to be glycol-water), to prevent ground freezing.

Table 2. Selected input data of nominal installed capacity, demand, and supply temperature for the GSHP equipment in the 5GDHC model, based on available data of the actual buildings (label in brackets stands for the sub-model prosumer station name associated to each actual building)

		Building (Prosumer station)				
		1a (GELA)	1b (GELB)	2 (ESP)	3 (ARA)	4 (GAR)
Heating and DHW	P_H^{nom} [kW$_t$]	805		191	249	307
	D_H^{nom} [MWh$_t$]	1203		159	270	390
	T_H^{supply} [ºC]	55		55	65	65
	D_{DHW}^{nom} [MWh$_t$]	147		107	15	21
	T_{DHW}^{supply} [ºC]	65	65	65	65	65
Cooling	P_C^{nom} [kW$_t$]		602			
	D_C^{nom} [MWh$_t$]		1786			
	T_C^{supply} [ºC]		-10			

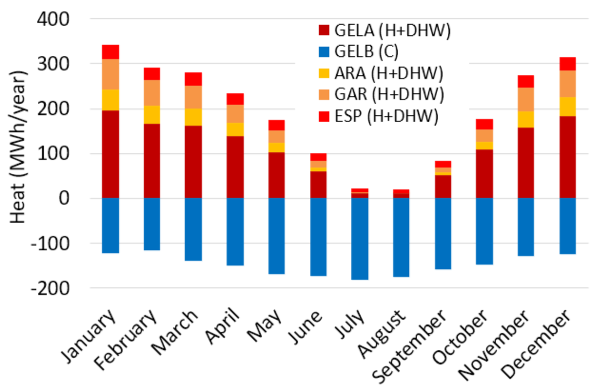

Figure 6. Monthly aggregated demands artificially generated based on actual buildings for modelling and simulation purposes.

3. RESULTS AND DISCUSSION

3.1. Hydrogeological context

The Quaternary sediments have been characterized along a thickness of 19.5 meters and have been grouped into three main units based on observations from the Quaternary materials characterization borehole.

- The first 3 meters are considered anthropogenic fill and topsoil.
- From 3 to 10 meters, alluvial deposits associated with Garonne River are observed, consisting of coarse to fine sands and clays with centimeter-scale gravels of variable lithology.
- Between 10 and 19.5 meters, compacted clays with sands and gravels are observed, interpreted as tills affected by slope processes.

Concerning bedrock materials, up to 103 m depth these are mainly composed of alternating Devonian shales and sandstones, which are fractured and contain quartz-filled veins, with different Rock Quality Designation-fracture intensity (RQD) index (between 10 to 80%).

Regarding hydrogeological characterization, the mini-pumping test (SXGV02) conducted in the Paleozoic bedrock aquifer (lower aquifer) yielded transmissivity values ranging from 0.47 to 0.61 m²/day, and hydraulic conductivity values between 8.6×10^{-8} and 1.1×10^{-7} m/s. The test was performed at a flow rate of 0.11 L/s, resulting in a total drawdown of 9.4 m in the groundwater level (Figure 7).

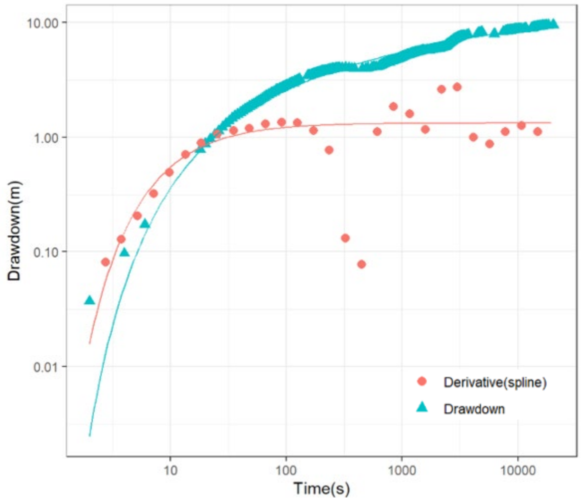

Figure 7. Drawdown and drawdown derivative curves from the hydraulic pumping test conducted in borehole SXGV02. Points represent measured data, while lines indicate the corresponding fitted drawdown curves.

As for the thermal properties of the subsurface, a summary is provided in Table 3. Based on the interpretation of the conventional TRTs, subsurface temperatures (T_g) ranged from 10 to 12 °C, with an average of 10.2 °C. This value is considered representative of the undisturbed ground temperature (T_g^0) at the site. The effective λ_g, also derived from the TRT interpretation, ranged between 3.70 and 3.96 W/mK, while α_g values were found to lie between 0.126 and 0.137 m²/d. Finally, the inferred value of v_{gw} is found to be in the range of 0.12 – 0.13 m/d.

Table 3. Resulting values of the averaged effective λ_g and α_g, and the averaged (inferred) v_{gw}, for both test boreholes SXGV01 and SXGV03.

	Method	SXGV01	SXGV03
$\bar{T}_g$ [ºC]	TRT	10.2	10.2
$\bar{\lambda}_g$ [W/mK]	TRT	3.70	3.94
	DTRT	3.96	3.85
	ADTRT	3.74	-
$\bar{\alpha}_g$ [m^2/d]	TRT	0.126	0.137
$\bar{v}_{gw}$ [m/d]	DTRT	0.12	0.13
	ADTRT	0.13	-

The interpretation of fiber optic data from the DTRT yielded consistent results. The spatially resolved distribution of λ_g values is presented in Figure 9. According to the DTRT profiles for boreholes SXGV01 and SXGV03, a local peak in thermal conductivity was observed at a depth of approximately 10 m, which may indicate a preferential groundwater flow path. At greater depths, λ_g values in SXGV01 show a slight increasing trend, while in SXGV03 no clear pattern is identified, despite exhibiting greater variability.

In the case of the ADTRT results for SXGV01, the estimated λ_g values display noticeable differences compared to those obtained with the DTRT method. However, the two datasets are broadly consistent: both highlight a near-surface peak (likely to correspond to Quaternary deposits) and an overall increase in conductivity with depth. This trend aligns with the possibility of enhanced fracturing and potentially higher groundwater flow in deeper strata.

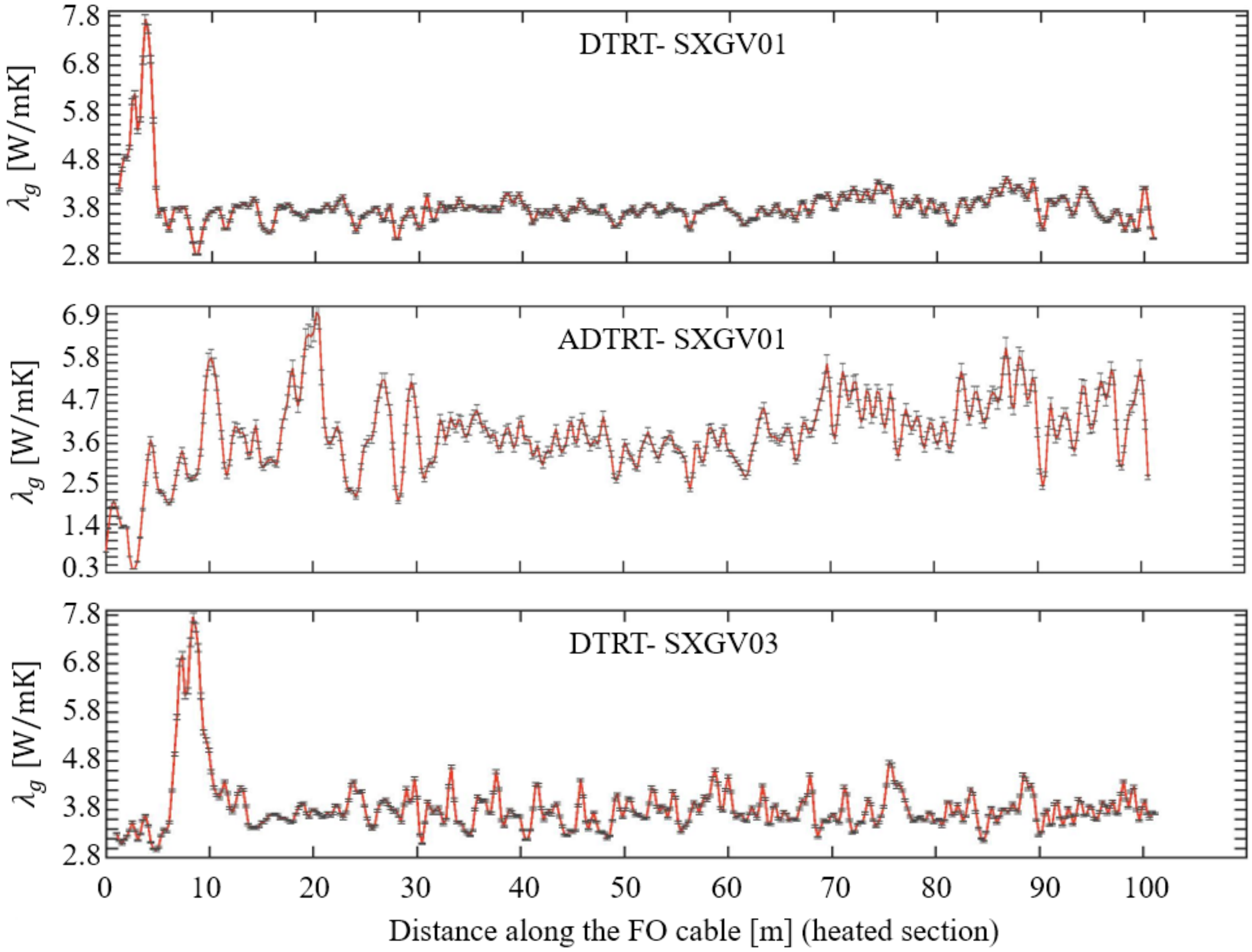

Figure 8. Spatially resolved values of ground thermal conductivity (λ_g) estimated from fiber optic temperature measurements taken every 0.25 m during a conventional Thermal Response Test (DTRT approach) and in the ADTRT performed specifically in borehole SXGV01.

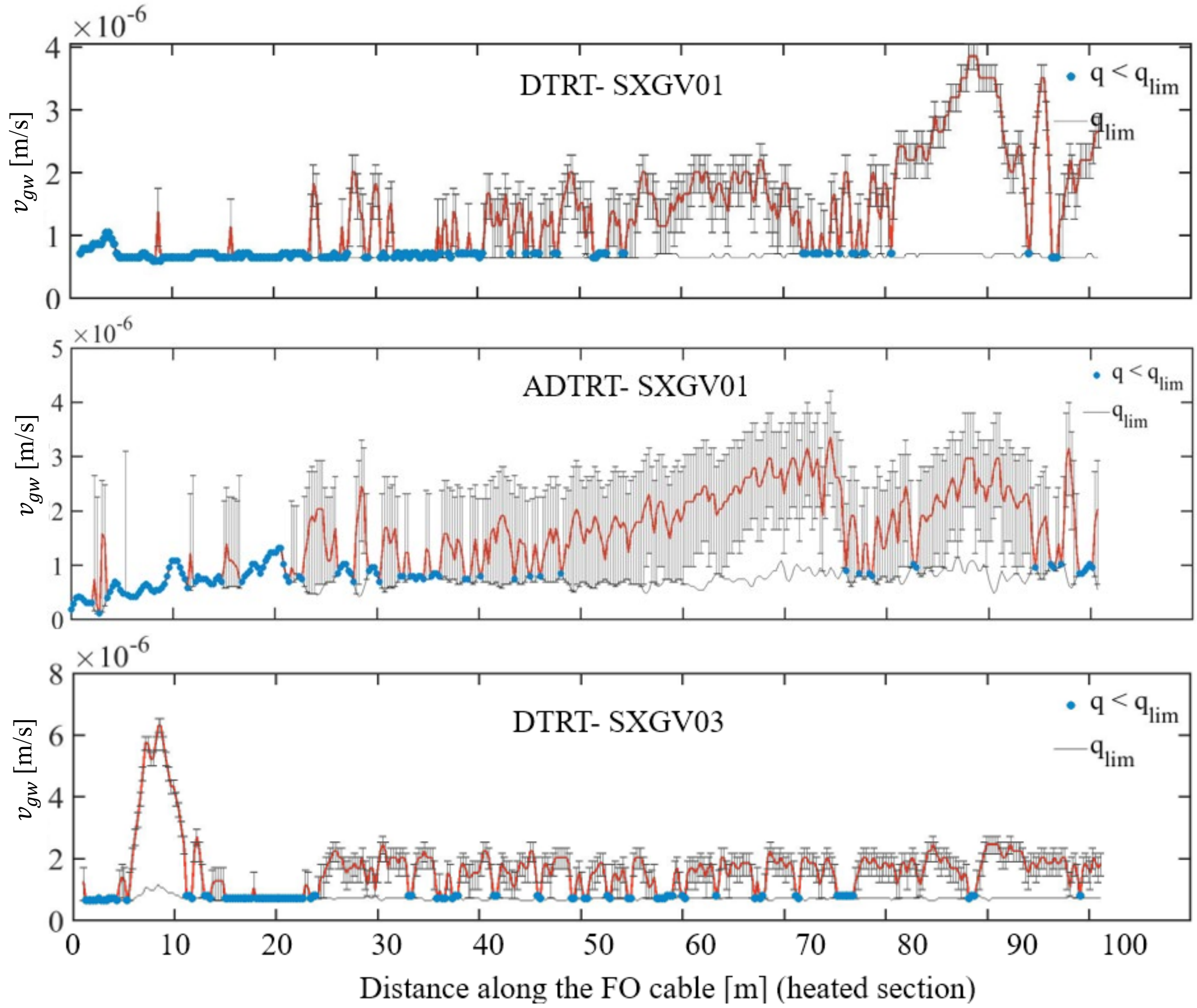

Figure 9. Spatially resolved inferred values of ground water flow velocity (v_{gw}) estimated from fiber optic temperature measurements taken every 0.25 m during a conventional Thermal Response Test (DTRT approach) and in the ADTRT performed specifically in borehole SXGV01.

Regarding the inferred groundwater flow velocity (v_{gw}), a similar depth-dependent pattern was observed. In SXGV01, v_{gw} increases with depth, suggesting more pronounced fracturing zones, whereas in SXGV03, the distribution is more uniform, with a shallow peak around 10 m. These results are also depicted in Figure 9.

In all cases, the v_{gw} values are considered high enough to suggest that advective heat transport cannot be neglected (Nguyen et al., 2017; Pandey and Basu, 2023), further reinforcing the need for a 3D coupled groundwater and heat transport model. While the results point to limited suitability for implementing a BTES system, it remains unclear whether heat restoration strategies would be required to compensate for long-term thermal imbalances.

3.2. Resulting network model

The Modelica-based simulation developed for this study conceptualizes a flexible and low-temperature 5GDHC network structured as a single-pipe ring (see Figure 10). A central pumping station regulates the overall network flow using a variable-speed pump, dynamically adjusting to the net demand across the system. Each prosumer building is equipped with its own dedicated pump, enabling the extraction or injection of thermal fluid from or into the ring to operate the corresponding heat pump system.

The system includes 6 prosumer stations, among which the ice rink and swimming pool are treated as separate entities. All prosumer stations are connected to a common thermal loop, thermally coupled with the surrounding soil through uninsulated pipes, allowing for passive heat exchange with the ground. The network is also designed to be expandable, enabling future interconnection with adjacent ring systems to explore synergies – for instance, connecting heating-dominated and cooling-dominated sectors. While this interconnection concept is in progress, its control strategy is yet to be fully defined, with the intended aim of achieving mutually beneficial energy exchange.

The borefield acts as the balancing unit (BU) of the network. Heat exchange with the ground occurs only when the network fluid temperature falls outside a predefined range (e.g., 5 – 15 °C). Ideally, when heating and cooling demands are balanced and occur simultaneously, the fluid temperature remains within this range, eliminating the need to circulate water through the borefield and thus reinforcing its role as a passive thermal buffer.

The borefield model used in this study is adapted from the `Buildings.Fluid.Geothermal.Borefields.OneUTube` component from the MBL. It allows for user-defined vertical discretization and computes g-functions according to the number and geometric arrangement of the boreholes. The model assumes constant and isotropic thermal properties for both the ground and grout. While the influence of groundwater advection is not explicitly represented in this version of MBL, its effect is implicitly captured through the effective thermal conductivity (λ_g) values derived from the TRT and DTRT analyses.

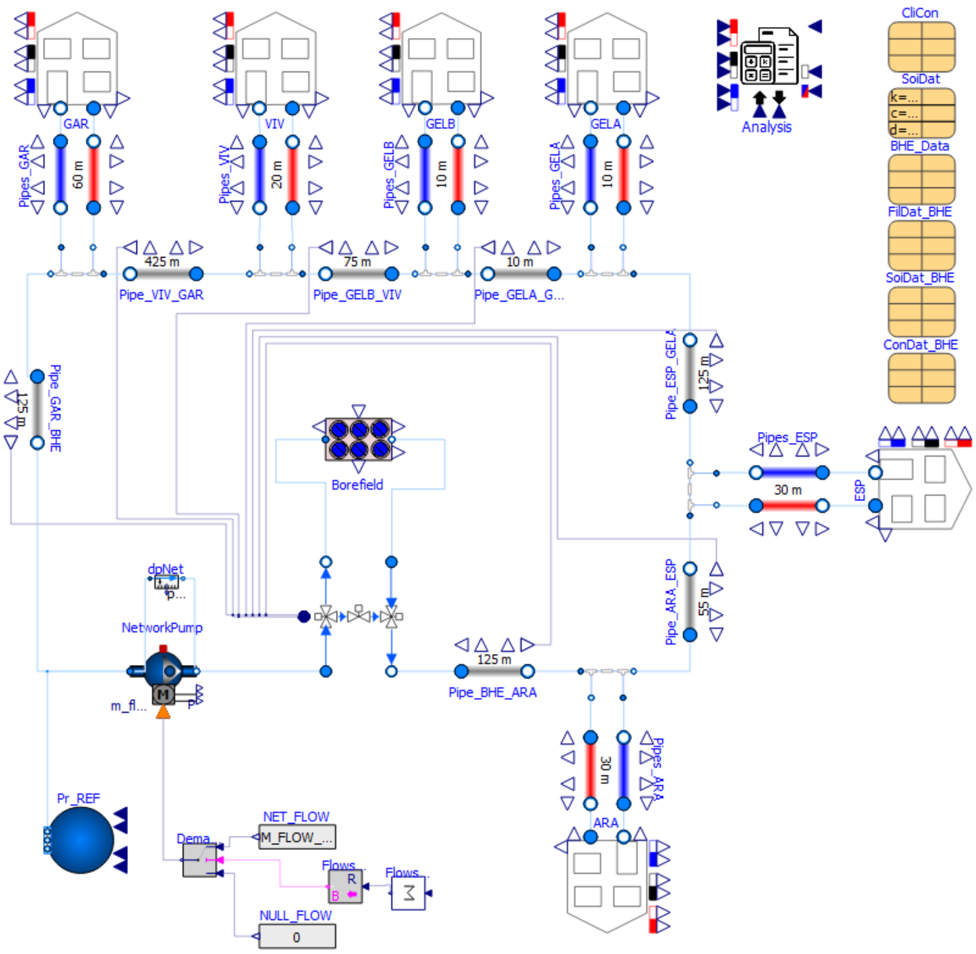

Figure 10. Top-layer graphical representation of the Modelica model simulating a hypothetical 1-pipe 5GDHC network, potentially deployable in Vielha. The prosumer station "VIV" does not correspond yet to an actual building.

Each prosumer station includes a simplified sub-model of a ground-source heat pump (GSHP) unit, based on a fixed-speed reciprocating compressor and operating under an ON/OFF control strategy. Thermal demands for DHW, space heating and cooling are fed into the system as hourly-average power demands. Direct heat exchange is assumed between the building-side and network-side loops, with internal heat recovery prioritized over other modes. Figure 11 illustrates an example of the model operation within a prosumer station. The internal control logic is based on an ON/OFF strategy, where the heat pump operates until the hourly thermal demand is met. In cases of simultaneous heating, DHW, and/or cooling demands, the model prioritizes DHW production over space heating, and heat recovery over independent heating or cooling modes.

The ring-loop itself is represented by single thermally active pipes (no thermal insulation) simulated using the `Buildings.Fluid.FixedResistances.Pipe` MBL component. The ground is modelled as a thermal sink with seasonal temperature variation following Kusuda's expression, though long-term thermal drift due to cumulative heat injection/extraction is not included. Sensors have been integrated throughout the model to capture key indicators such as fluid temperatures, pressure drops, and heat transfer with the ground, enabling detailed monitoring and post-processing.

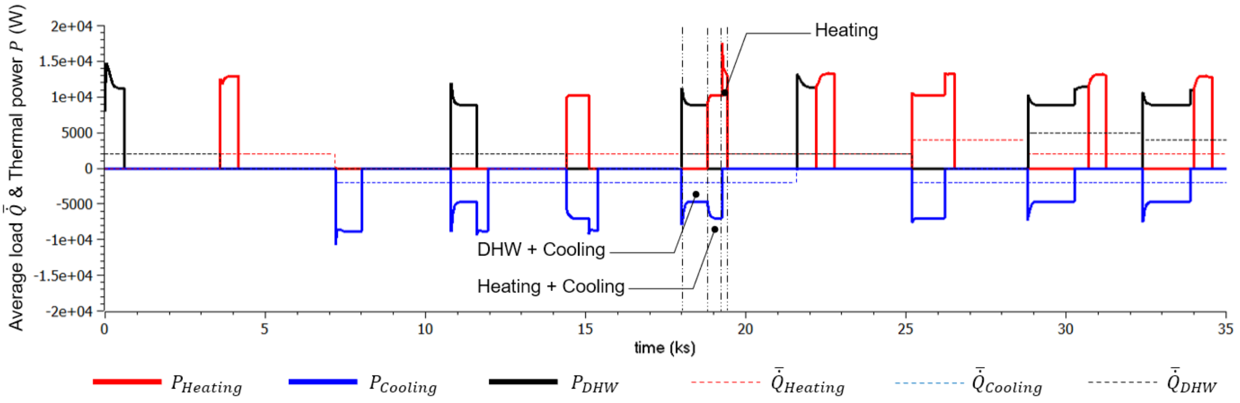

Figure 11. Example of heat pump operation in a prosumer station under varying hourly demand scenarios. Dashed lines represent average load values, while solid lines illustrate the part-load behavior of the heat pump model, highlighting its prioritization logic when simultaneous heating, DHW, and/or cooling demands occur within a given hour.

4. CONCLUSIONS

This study presents the first stage of a broader effort to design a 5GDHC network powered by SGE and PVSE in the town of Vielha, located in the Catalan Pyrenees. An extensive fieldwork campaign was conducted to characterize the hydrogeological context of the site. Based on the lithological data collected, the results revealed higher-than-expected values of effective thermal conductivity ($\lambda_g \geq$ 3.7 W/mK) in the subsurface, which is likely influenced by the presence of groundwater.

Preliminary interpretations suggest that a BTES system may not be the most suitable solution due to the advective effects identified (v_{gw} >$1 \cdot 10^{-6}$ m/s). However, the potential role of seasonal heat restoration strategies to address long-term thermal imbalances remains an open question and will be explored further.

Despite these early findings, important uncertainties persist regarding groundwater flow direction, velocity, and their interaction with subsurface heat transport. For this reason, a three-dimensional coupled groundwater and heat flow model is currently under development and will provide the necessary input for the heat exchange configuration of the final system.

In parallel, a dynamic model of a 5GDHC network has been developed using the Modelica language. The model incorporates representative thermal demand profiles of several public buildings and simulates a one-pipe ring layout with a central borefield acting as a BU.

5. FUTURE WORK

While this paper presents the conceptual framework and key components of the 5GDHC model, a detailed technical description and performance evaluation will be addressed in a dedicated follow-up publication. This will also include the integration of photovoltaic energy generation and an in-depth analysis of the heat restoration concept.

Future work will also investigate alternative configurations, such as fourth-generation district heating networks (4GDH) based on centralized ground source heat pump (GSHP) systems operating through four-pipe layouts.

REFERENCES

Abugabbara, M., Alberdi-Pagola, M., Javed, S., Poulsen, S.E., 2022. Integration of ground-source heat pumps in combined district heating and cooling networks: A holistic modeling framework, in: European Geothermal Congress. Presented at the European Geothermal Congress 2022, Berlin, pp. 1–9.

Banks, D., 2012. The Design of Groundwater-Based Open-Loop Systems, in: An Introduction to Thermogeology: Ground Source Heating and Cooling. pp. 202–247. https://doi.org/10.1002/9781118447512.ch8

Carslaw, H.S., Jaeger, J.C., 1959. Conduction of Heat in Solids. Oxford University Press, USA.

Casasso, A., Sethi, R., 2016. G.POT: A quantitative method for the assessment and mapping of the shallow geothermal potential. Energy 106, 765–773. https://doi.org/10.1016/j.energy.2016.03.091

Hinkelman, K., Wang, J., Zuo, W., Gautier, A., Wetter, M., Fan, C., Long, N., 2022. Modelica-based modeling and simulation of district cooling systems: A case study. Applied Energy 311, 118654. https://doi.org/10.1016/j.apenergy.2022.118654

ICGC, 2024. Xarxa de mesura de paràmetres hidrogeològics i geotèrmics (Projecte Vielha SMART) [WWW Document]. URL https://www.icgc.cat/en/node/23516

LBNL, 2024. Modelica Buildings Library – Download [WWW Document]. URL https://simulationresearch.lbl.gov/modelica/download.html

Mans, M., Blacha, T., Schreiber, T., Müller, D., 2022. Development and Application of an Open-Source Framework for Automated Thermal Network Generation and Simulations in Modelica. https://doi.org/10.3390/en15124372

Nguyen, A., Pasquier, P., Marcotte, D., 2017. Borehole thermal energy storage systems under the influence of groundwater flow and time-varying surface temperature. Geothermics 66, 110–118. https://doi.org/10.1016/j.geothermics.2016.11.002

Pandey, U., Basu, D., 2023. Effect of groundwater flow on thermal performance of SBTES systems. Journal of Energy Storage 74, 109375. https://doi.org/10.1016/j.est.2023.109375

Simon, N., Bour, O., 2023. An ADTS Toolbox for Automatically Interpreting Active Distributed Temperature Sensing Measurements. Groundwater 61, 215–223. https://doi.org/10.1111/gwat.13172

Simon, N., Bour, O., Lavenant, N., Porel, G., Nauleau, B., Pouladi, B., Longuevergne, L., Crave, A., 2021. Numerical and Experimental Validation of the Applicability of Active-DTS Experiments to Estimate Thermal Conductivity and Groundwater Flux in Porous Media. Water Resources Research 57, e2020WR028078. https://doi.org/10.1029/2020WR028078

Sutton, M.G., Nutter, D.W., Couvillion, R.J., 2003. A Ground Resistance for Vertical Bore Heat Exchangers With Groundwater Flow. Journal of Energy Resources Technology 125, 183–189. https://doi.org/10.1115/1.1591203

Wetter, M., Fuchs, M., Grozman, P., Helsen, L., Jorissen, F., Lauster, M., Mueller, D., Nytsch-Geusen, C., Picard, D., Thorade, M., 2015. IEA-EBC Annex 60 Modelica Library – An International Collaboration to Develop A Free Open-Source Model Library for Buildings And Community Energy Systems, in: Proceedings of BS2015. Presented at the Conference of International Building Performance Simulation Association, Hyderabad, India. https://doi.org/10.26868/25222708.2015.2414

Wirtz, M., 2023. nPro: A web-based planning tool for designing district energy systems and thermal networks. Energy 268, 126575. https://doi.org/10.1016/j.energy.2022.126575

Zubair, S.M., Chaudhry, M.A., 1996. Temperature solutions due to time-dependent moving-line-heat sources. Heat and Mass Transfer 31, 185–189. https://doi.org/10.1007/BF02333318

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