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Strategies and potentials of temperature reduction on existing district heating networks: two case studies

SWEET DeCarbCH
Deliverable D7.1.1 Auditing method for existing district heating substations

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Summary

DeCarbCH “Decarbonisation of Cooling and Heating in Switzerland” project addresses the colossal challenge of decarbonisation of heating and cooling in Switzerland within three decades. Within this project, Work Package 7 focuses on temperature reduction in district heating (DH), which is a priority for integration of renewable and waste heat, a crucial point to lower the carbon content of DH systems that are key components for the energy transition. More specifically, Task 7.1 tackles the issue of temperature reduction techniques at substation/demand level. Focus is set on case studies of existing district heating systems, in urban and rural context.

The first case study is CAD-SIG in Geneva, one of the main DHN in Switzerland, built and extended since the 1960’s and delivering 359 GWh/year of heat. The second one is CAD Le Marais Rouge in les Ponts de Martel (NE), deployed in 2007 and supplying 6 GWh/year of heat. Both are supplying heat mostly to existing residential buildings from the 20th century, but their temperature levels are quite different. The supply/return temperatures in winter reaches typically 110/70°C for CAD-SIG, while they are 80/40°C in CAD Le Marais Rouge.

In order to achieve lower temperatures in existing DH systems, the first step is to rank all the substations by their influence on the primary return temperature. The excess flow method seems to be the most common and easy tool to do so, based on each substation’s energy and volume use data. This allows detecting temperature errors and prioritizing interventions between substations. We perform this pre-analysis on both DH case studies and show first results of their substation’s ranking, and provide auditing and visiting checklists for district heating substations, in order to look for the most obvious situations that could cause high return temperatures on DH.

According to the literature, the majority of temperature errors in substations are due to set points and control problems as well as problems with components in the secondary circuit. This second point is delicate, since in most cases, the secondary part of the substation is owned and operated by the customer. This may require additional data collecting or complementary monitoring to understand substation’s operation and explain high primary return temperature sources.

Table of contents

List of Figures

List of Tables

List of abbreviations and acronyms

DeCarbCH	Decarbonisation of Cooling and Heating in Switzerland
DH	District heating
DHN	District heating network
DHW	Domestic hot water
ERA	Energy reference area
HP	Heat pump
oe	Oil equivalent
SH	Space heating
SIG	Services industriels de Genève
SITG	Système d'Information du Territoire à Genève
SST	Substation
SWEET	SWiss Energy research for the Energy Transition
WP	Work package
ΔT	Temperature delta (between supply-return temperatures)
ΔT_{ref}	Target temperature delta

1. Introduction

This work takes place within SWEET DeCarbCH “SWiss Energy research for the Energy Transition – Decarbonisation of Cooling and Heating in Switzerland”, a research project sponsored by the Swiss Federal Office of Energy and coordinated by the University of Geneva.

DeCarbCH aims to facilitate, speed up and de-risk the implementation of renewables for heating and cooling in the residential sector (for various scales and degrees of urbanization) as well as for the service and the industry sector, in order to achieve decarbonisation of heating and cooling in Switzerland in the next decades. DeCarbCH focuses on advanced renewable energy and transformation technologies, thermal grids (for heating and cooling), and energy storage, with the purpose of establishing optimal combinations (in technical, economic and environmental terms) as well as necessary and desirable conditions for their implementation.

DeCarbCH is organised in several Work Packages (WP), of which WP 7 focuses on reduction of temperature in district heating (DH), as this is a priority for integration of renewable heat. While DH supply temperatures are generally under DH operators’ control, this is usually not the case for return temperatures, which depends on the temperature level of the individual substations, on the secondary side of the heat exchanger (distribution/demand). Latter issue is of particular concern in the case of existing buildings, where distribution temperatures are known to be high, and where corrective actions within inhabited spaces is of particular complexity (especially for multifamily buildings). Several techniques for temperature reductions at substation level have been proposed or are currently under investigation, but their actual implementation on existing DH substations (SST) depends to a large extent on pre-existing conditions. Furthermore, the actual benefit of temperature reduction at the level of the district heating network (DHN), as well as interaction between temperature reduction strategies and other energy policy measures, need to be analysed on specific case studies.

Within this WP 7, these issues will be tackled by way of case studies on existing DH systems, in urban and rural context. The WP is structured along following tasks:

- Task 7.1: Temperature reduction in existing DH substations;
- Task 7.2: Impact of different temperature lowering strategies at the level of DH networks;
- Task 7.3: Interaction between temperature reduction strategies and other energy policy measures;
- Task 7.4: Comparison of different measures and governance arrangements for the implementation of temperature reduction strategies.

As a first step, Task 7.1 tackles the issue of temperature reduction techniques at substation/demand level. This could include optimization/control of flowrates and heat exchanger sizes, cascade production of SH and DHW, instantaneous DHW production (without storage) for suppression of legionella issues, use of decentralized compression or sorption HPs (with heat sources on primary and/or secondary sides of the SST heat exchanger), decentralized temperature boosting by way of classical techniques (fossil, electric), etc. Focus will be set on case studies of existing DH systems, in urban and rural context, for which we will work in close collaboration with selected cooperation partners. Task 7.1 is organized around the following activities:

- development and testing of an auditing method for existing SST (SH and DHW loads and temperature levels, SST architecture / components);
- comparative analysis of alternative techniques for substation temperature reduction (literature review, numerical simulation, test bench);
- proposal and definition of P&D projects, for implementation by/with our cooperation partners.

In this delivery, we provide a literature overview about the interest of lowering DH temperatures, example of temperature errors sources in substations causing high primary return temperatures on DH, as well as possible solutions. We describe the selected cases studies, the available and collected data. We developed auditing and visiting checklists for district heating substations, in order to assess their possible impact on the district heating network working temperatures. We show first results of the network substations ranking by their influence on the district heating network primary return temperature.

2. Literature review

2.1 Interest of temperature reduction in DH

Lowering temperature levels of DH has multiple benefits [1]:

- Integration of renewable heat into DH (solar thermal, geothermal, heat pumps, waste heat, etc.);
- Improvement of heat production or recovery efficiencies (depends on heat sources for DH);
- Reduction of heat losses from DH;
- Alternative materials and techniques available (pre-insulated flexible pipes, which imply a faster and easier installation).

Moreover, all these elements offer a potential reduction of the heat costs with low temperature networks, according to a gradient that depends on the heat production technology. For existing cases, this cost reduction gradient varies from 0.67-0.68 EUR/MWh/°C for low temperature geothermal, 0.63-0.67 EUR/MWh/°C for heat pumps, 0.10-0.13 EUR/MWh/°C for biomass boilers with flue gas condensation [2].

Finally, the improvements, actions, and conditions needed to achieve low-temperature heat networks are already well identified [3]. Roadmaps exist, summarizing the different steps, of which the main ones are: resolving temperature errors in networks and substations, using exchangers with large thermal lengths, reducing temperature requirements at customer level, with a long-term perspective [1].

2.2 Temperature levels in DH networks

Operating temperatures of the main DH networks in Switzerland show that the largest of them are still 2nd or 3rd generation networks, with high distribution temperatures. Figure 1 shows a benchmark of supply & return temperatures of the main DH networks in Switzerland, depending on the amount of heat supplied [4]. It can be seen that the largest networks in terms of the amount of heat delivered are those with the highest flow temperatures (90-110°C), and that even networks with relatively low supply temperatures (60-70°C) do not necessarily have low return temperatures.

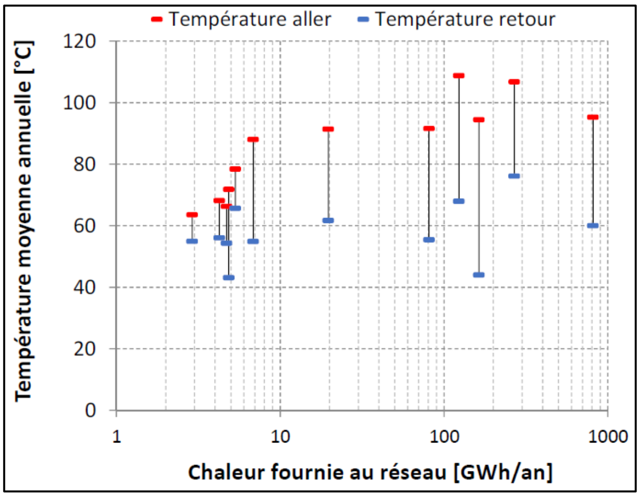


Figure 1 - Temperature levels of Switzerland's main district heating networks. Horizontal axis: annual delivered heat [GWh/year], vertical axis: yearly average supply-return temperatures [°C]. Source: [4].

Figure 2 shows the average supply & return temperatures for heat networks in Sweden (86/47°C) and Denmark (78/43°C), as well as the achievable temperatures for 3rd generation networks (70/35°C), according to the currently available technology [1]. In comparison, large Swiss heat networks therefore have significant potential to lower their operating temperatures while remaining within an achievable target for 3rd generation networks with the current state of the art.

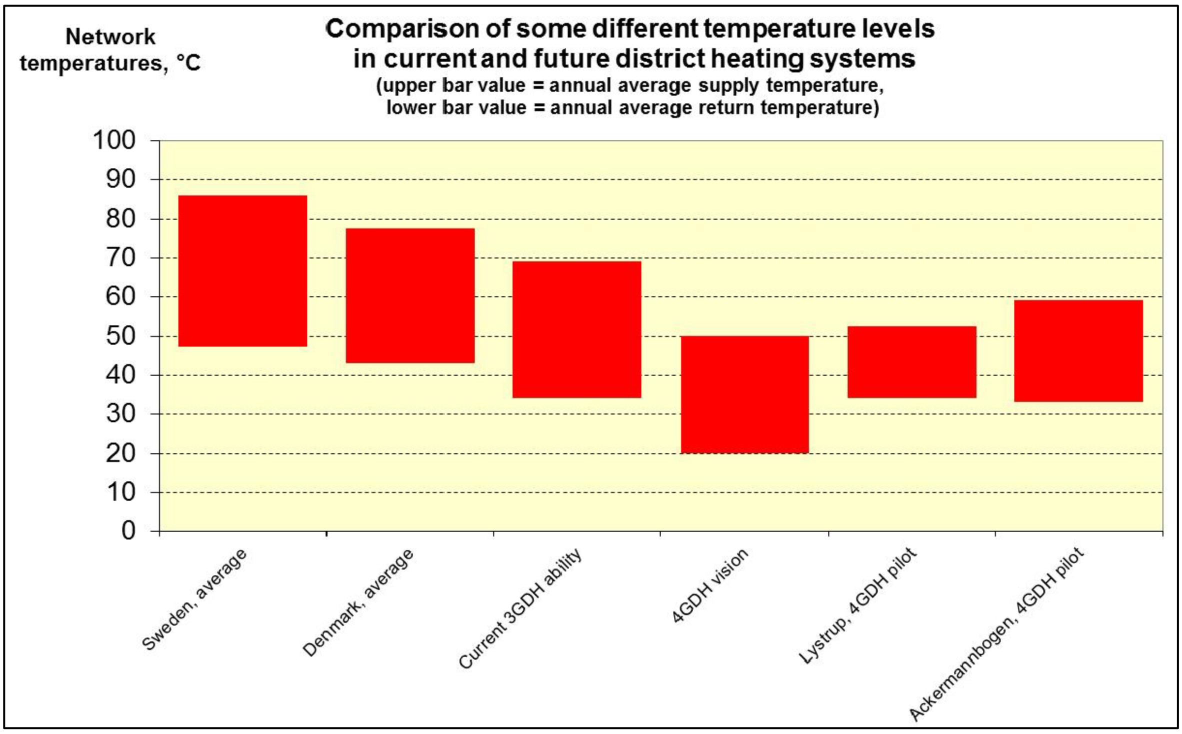


Figure 2 - Comparison of temperature levels in district heating systems. Source: [1].

As can be seen, several networks are already operating at low temperatures, including for pre-existing networks that have been adapted, with case studies available listing their particularities and knowledge gained [5].

2.3 Distribution temperature levels in buildings

With respect to heat demand, required temperature levels follows the building requirements for space heating (SH) and domestic hot water (DHW) production. In Geneva, a study measured supply and return temperatures for SH [4]. SH supply temperatures are displayed in Figure 3. For an outdoor temperature of -5°C, typical SH supply-return temperatures are as follows:

- For systems with radiators (sample of 110 SH circuits), supply temperatures are typically 55-60°C, and return temperatures between 46-53°C;
- For systems with underfloor heating (sample of 18 SH circuits), supply temperatures are typically 33-44°C, and return temperatures between 28-36°C.

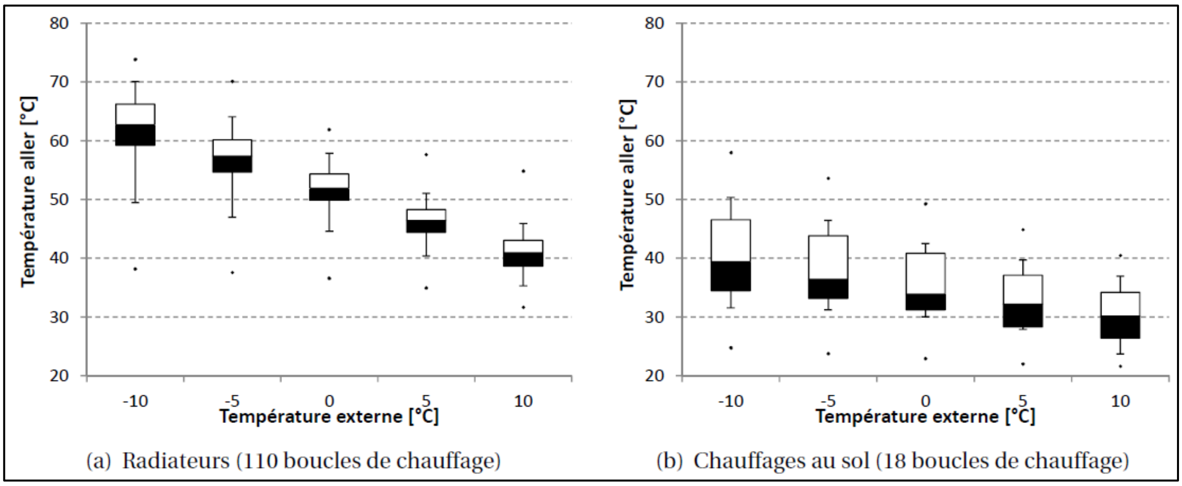


Figure 3 - Typical SH supply temperatures in Geneva multifamily residential buildings, with (a) radiators and (b) floor heating [4].

The results of this study indicate that temperature levels for SH are mostly lower than those for DHW production in these buildings. However, "[...] return temperature differences are often too small, indicating excessively high flow rates that may be caused by lack of thermostatic valves, oversized or improperly adjusted circulating pumps, or improper balancing of hydraulic circuits." [2].

The production of DHW thus becomes a critical point of the substation in terms of temperature levels, which can be explained, among other things, by the constraints aimed at avoiding the development of legionella. Moreover, the fact that the relative share of DHW will increase as the SH demand decreases (renovation, new construction) should also draw attention to the influence of DHW production on substation performance.

2.4 Temperature error detection and SST prioritization

There are two levels of analysis to consider for DH temperature optimization. The first one is the DH level, with a global view of all the substations, in order to identify the problematic ones and prioritize the interventions. The second level relates to the substation (after selection) and concerns the study of its operation, which includes the heat distribution part for the building. The excess flow method (overflow method) allows classifying all the substations of a heating network according to the excess flow they use, as compared to a situation where they would operate with a target temperature difference (supply - return). Figure 4 shows an example of an analysis with this method [6].

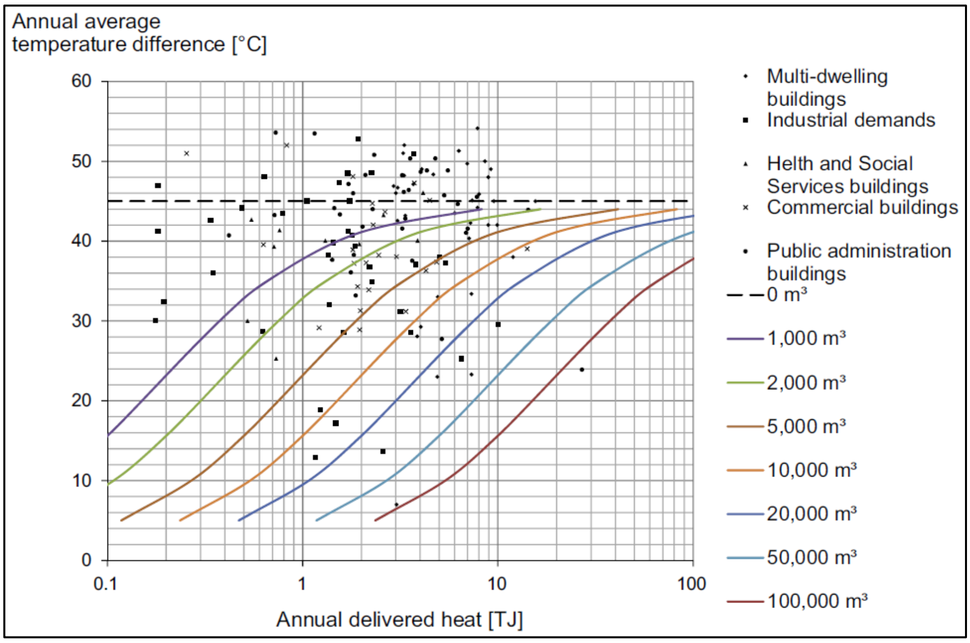


Figure 4 - Example of substation analysis using the excess flow method. Each point represents a substation connected to the DH, with its annual heat demand and annual average temperature delta. The substations in the lower-right part of the graph are the most problematic, with high energy demand combined to high excess flow relative to the targeted temperature delta (here 45°C, horizontal dashed line). Source: [6].

This simple method requires little data (volume and heat consumed annually by each substation, choice of a target temperature delta (ΔT_{ref}) and quickly allows targeting substations to be optimized as a priority. A description of the method and an Excel tool are available online specifically for conducting this analysis [7]. Latter also lists a series of recommendations as part of the substation analysis, which are summarized as follows:

- Centralize the collection of substation energy metering data. Record the amount of heat and volume used;
- Evaluate substations with the excess flow method. If data is readily available, the time required for analysis is low;
- Analyze substations periodically to quickly identify operating deviations, ideally once a month;
- Clarify optimization needs on site with qualified personnel, and in coordination with the connected customer. Rank possible measures according to their costs and benefits;
- Distinguish between what is the responsibility of the supplier and what is the responsibility of the connected customer, and what are respective advantages and disadvantages for both parties in the implementation of optimization measures;
- Check the results after optimization to validate improvements.

On the other hand, although simple and effective, the excess flow method only allows the ex-post detection of temperature errors in the substations, with a time lag that depends on the frequency of the analysis. A monthly monitoring of substations with this method probably offers a good reactivity compared to an annual monitoring, but there are also alternatives allowing a quick detection of errors in substations within a few days.

The temperature difference signature method [6] relies on daily substation heat meter data (energy and volume) to plot a signature of substation temperature delta (ΔT) as a function of outdoor temperature (cf. Figure 5). This requires good quality substation data, automatic daily processing, and choice of reference substations (whose operation is considered optimal).

In return, this method allows to detect temperature errors on a daily basis, as well as to ensure the follow-up of the corrections. This method could also be applied outside the SH period (outdoor temperature above 10°C), a period in which the ΔT is generally low because it is influenced only by the production of DHW. But the diversity of signatures in this period is such that it would be necessary to define an acceptable range of variation for each substation. Figure 5 shows an example of a ΔT signature for a substation [6].

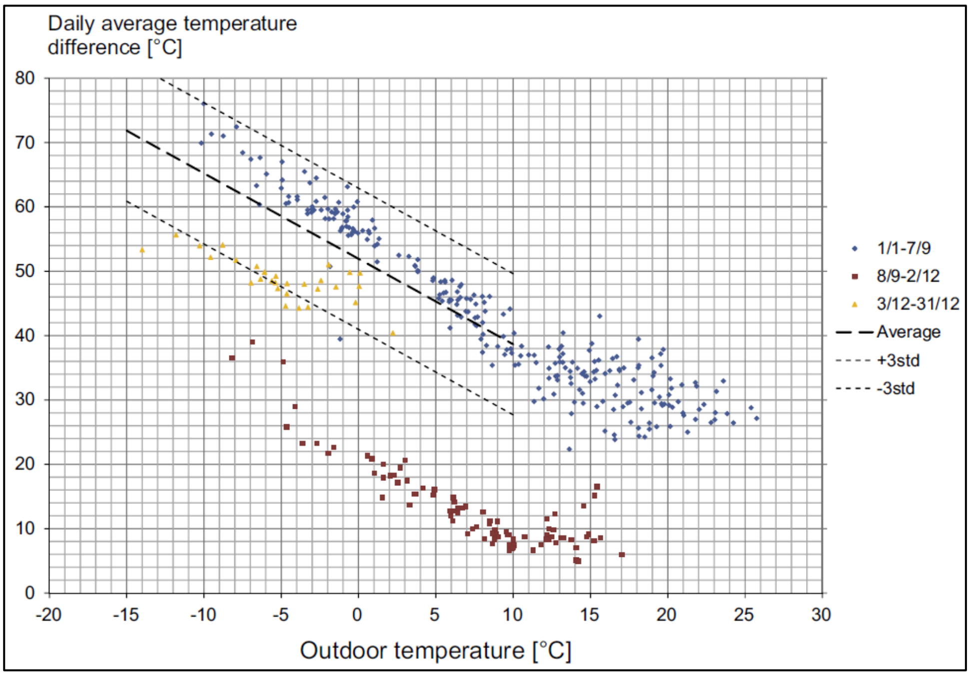


Figure 5 - Example of a temperature difference signature for a substation. An operating fault is clearly visible (red dots), compared to normal operation (blue dots). The error was subsequently corrected (yellow dots), but the substation obviously did not recover its previous performance. Source: [6].

Other data representations or monitoring indicators can be used, for example with the specific flow rate of the substations (m^3/MWh). This is a simple indicator to obtain if the energy and volume data from the heat meters are available, useful to follow the evolution of the substation operation following modifications or optimizations. An example on the CAD-SIG network between 2009 and 2014 shows that the specific flow rate of substations in the Lignon and Avanchets neighbourhoods was optimized and reduced by half, from about 50 m^3/MWh to 25 m^3/MWh [2]. But this indicator does not consider substation consumption, and therefore should not be used as a method for prioritizing interventions.

2.5 Errors and possible solutions to reduce temperature levels in substations

The origin of a malfunction causing high return temperatures can potentially come from each main component of a substation [8]: heat exchangers, valves, pumps, temperature and pressure sensors, flow meters, controlers, etc. The same study indicates that the most frequent errors are caused by problems in the control system, with following frequency ranking: parametrization errors, component malfunctioning, and substation construction errors. The simplest and cheapest to solve are (luckily) also the most frequent ones, i.e., inadequate settings of the control systems.

Averfalk et al. [5] classified 520 errors encountered in 246 Swedish substations, showing their frequency according to category type (Figure 6). Categories "Set-points and regulation" and "Faults in secondary side components" account for almost two-thirds of the errors encountered in the substations studied.

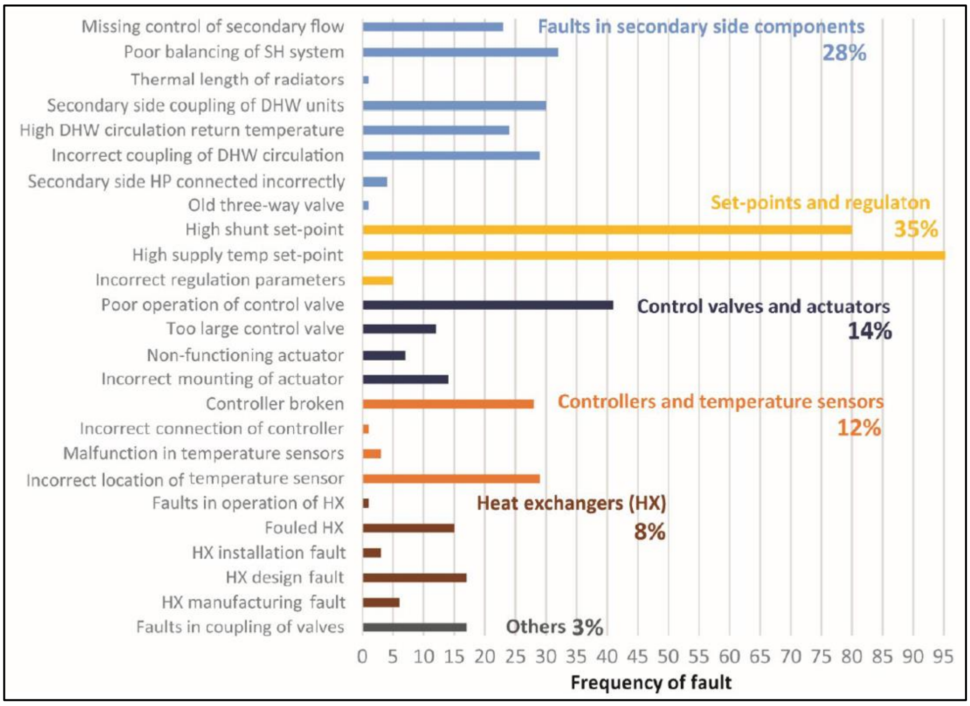


Figure 6 - Classification of errors encountered in 246 Swedish substations. Source: [5].

Li and Nord [9] describe the challenges of moving to 4th generation DH and identify possible errors causing high return temperatures in substations, their causes and possible solutions, as summarized in Table 1.

Table 1 - Causes and possible solutions for high return temperatures in substations. Source: [9].

Causes	**Description**	**Solution**
Short-circuit flows	Intentional short-circuit flows to maintain a minimum supply temperature, or avoid network freezing	Thermostatic bypass, or innovative systems to avoid bypass flow
	Unintentional short-circuit flows from remnants of construction, or from connection mistake	Improve the construction quality
Low supply temperature	Substation control with high flows to compensate the low supply temperature	Intentional short-circuit flows, three pipe system with two supply pipes and one return pipe
Errors in customer heating systems	Missing thermostatic valves in SH system, missing hot water circulation in DHW system, three-way diverting valves in the SH system	Add thermostatic valves in SH system, put the temperature sensor of DHW near or in the heat exchanger, replace three-way diverting valves with two-way valves
Errors in customer substations	Too small heat emitting surfaces in SH, ventilation and DHW system, which results in a large flow and low cooling	Choose suitable heat emitting surfaces
	Set point errors, secondary set point temperature set higher than the primary supply temperature, giving full primary flow	Intelligent control which can ignore impossible control situations
	Malfunction errors: leaking valves, defective valve motors, malfunctioning temperature transmitters, fouled heat transfer areas for heat exchangers	Use high quality equipment, apply fault detection technology, and regular maintenance
	Design errors: too large valves, wrongly assembled temperature transmitters, wrong valve motors chosen, parallel flow installations for heat exchangers, wrong heat exchanger size chosen, deviations from recommended substation configurations	Improve design quality, apply prefabricated equipment

The same article suggests that the process of reducing temperature levels in heat networks can be divided in two steps. The first one is to reach the currently achievable performance for the networks by removing operating errors and improving system monitoring, the second one requires improving the heat transfer stations through better design and exchangers with better performance [9]. Beyond the purely technical aspects, Månsson *et al*. state that the two most important elements to achieve low return temperatures are having the mandate and physical access to the customers' facilities, and maintaining a good proximity relationship with the consumers, because a large part of the errors occur in the building system for heat distribution. With these two elements, most of the frequent errors are easy to solve [10].

In view of the above considerations, the first solution to improve the temperature levels in the heating networks is to check the proper functioning of the substations by regular monitoring and checking the frequent sources of error when their performance is not satisfactory. Regarding the return temperatures of the heating systems, in the secondary side of the substations, it is also expected that an energy retrofit can achieve lower return temperatures, with further improvement possible in case of hydraulic balancing [2].

2.6 Substation architecture

As a complement to optimization of existing substations, there are also many possibilities for substation architectures that can improve the temperature levels of DH networks. A first level of differentiation is between the choice of a centralized substation for a building, or a system with decentralized substations in each apartment in the form of a thermal module (flat station, heat interface unit) allowing heat supply for SH and instantaneous DHW preparation [11].

Figure 7 shows different possibilities of substation architectures [11]. Type 3 is the most common in Geneva (however with DHW storage instead of instantaneous production), with an intermediate circuit including two exchangers in series. Type 2, with exchangers in parallel for SH and DHW is often used in Scandinavian countries, for reliability issues. In addition, this solution can better regulate the flow rates for SH and DHW production and help reduce return temperatures [4].

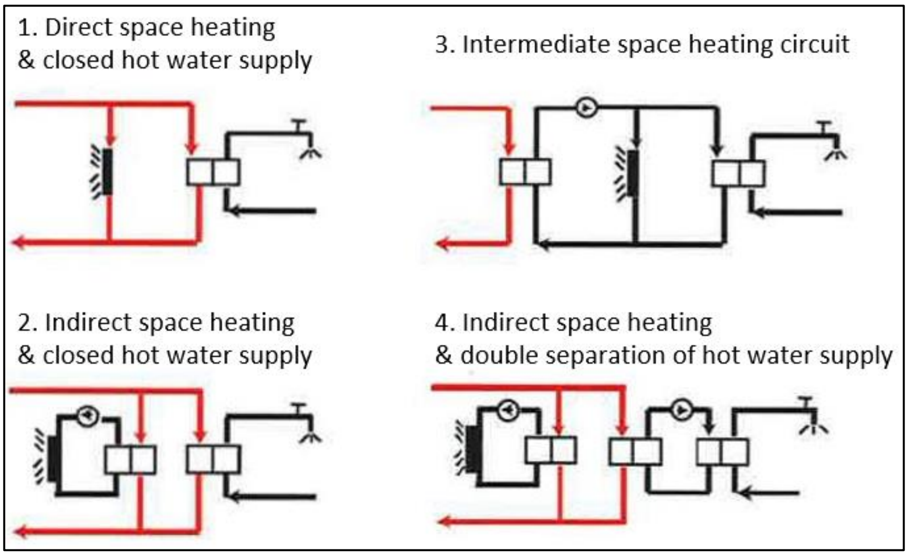
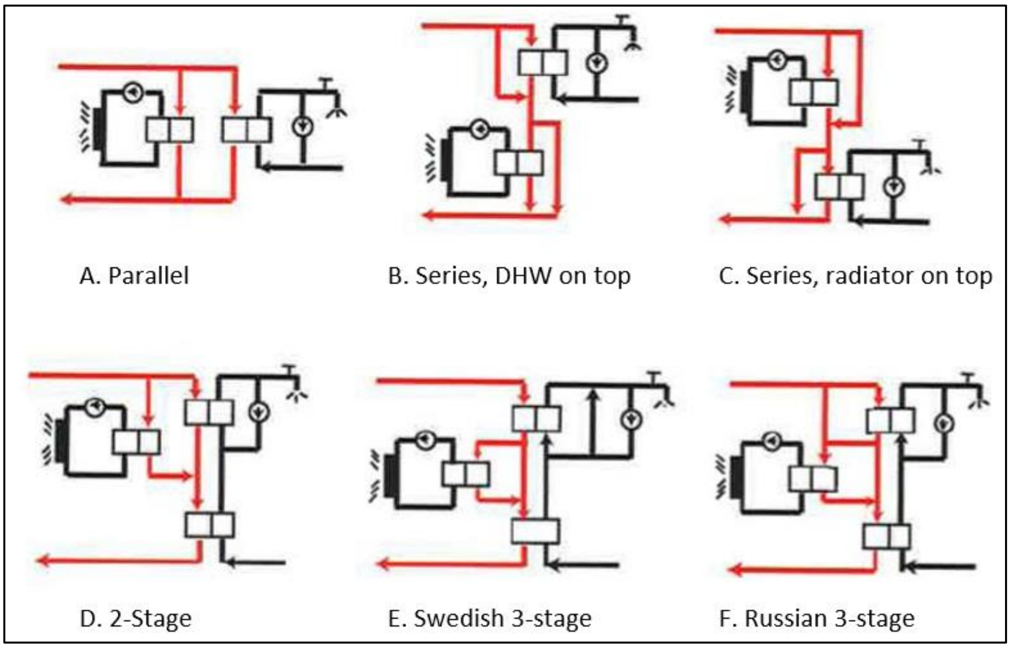


Figure 7 - Examples of substation architectures. Only instantaneous DHW production is illustrated, but different solutions are possible. Source: [11].

Further reduction of the return temperature can be achieved with cascade architecture solutions, but the gain is at first sight small, and the complexity increased compared to a relatively simple architecture with two exchangers in parallel (example A in Figure 19) well sized and well regulated.

Figure 8 shows some examples of cascaded architectures, with the parallel architecture shown above letter A [11].



A. Parallel

B. Series, DHW on top

C. Series, radiator on top

D. 2-Stage

E. Swedish 3-stage

F. Russian 3-stage

Figure 8 - Examples of cascaded architectures, with Example A with parallel architecture as a comparison. Only instantaneous DHW production is illustrated, but different solutions are possible. Source: [11].

As a summary, Averfalk *et al.* [2] gives us a list of possible actions to lower the temperature in SH systems and to lower the primary DH temperatures for DHW systems, ranked from low to high cost in Table 2.

Table 2 - List of possible actions to lower the temperature in heating systems. Source: [2].

	Space heating	Domestic hot water systems
	Installation of thermostatic valves	Improved DHW tank charging
Low costs	Hydronic system balancing	Reduce circulation heat losses – additional insulation, in-pipe solution
	Supply temperature optimisation	Disinfection
	Replacing inefficient heat exchangers	DHW circulation heat pump
↓	Replacing critical radiator	Flat stations for new buildings and deep energy renovation in buildings
	Replacing single-pipe heating systems with two-pipes systems	Additional electric heating for ultra-low temperatures
High costs	New low temperature radiators	
	Energy renovation (with or without new heating installations)	

3. Comparative description of district heating network case studies

In this chapter, we describe in a synthetic way the two case studies that are analysed in this report. Information such as location and technical characteristics are given.

The DHN selected as case studies are CAD-SIG[1] in Geneva (canton of Geneva) and CAD Le Marais-Rouge[1] in Les Ponts-de-Martel (canton of Neuchâtel), which localisation is given in Figure 9.

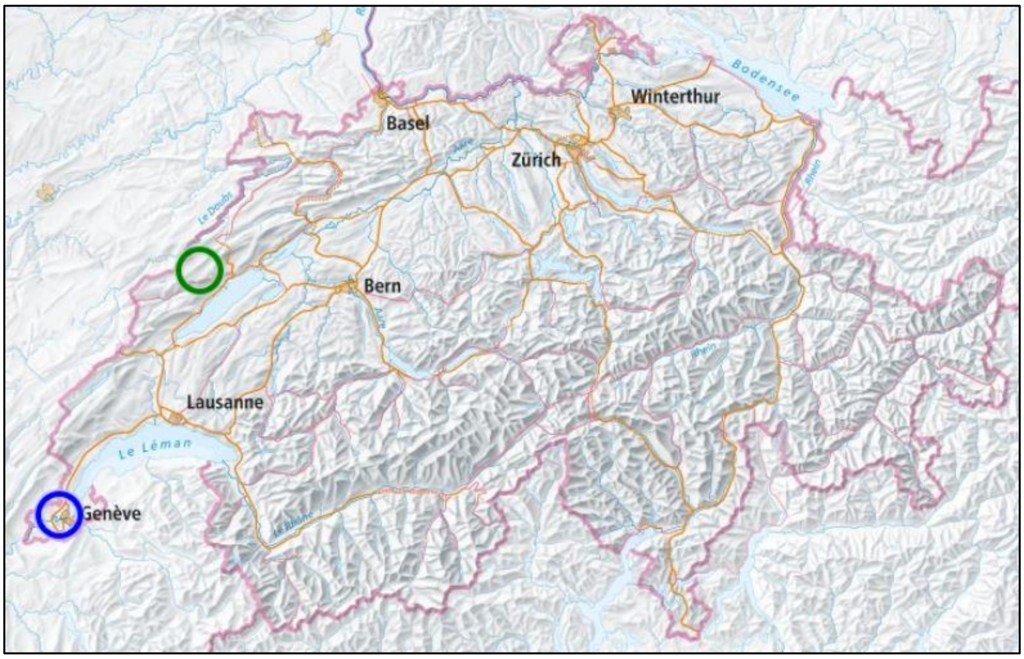


Figure 9 - Localization of the cases studies in Switzerland: CAD Marais-Rouge (green circle) and CAD-SIG (blue circle). Source: [13].

CAD-SIG is a relatively old DH network from the 60's with high supply/return temperatures around 110°C/70°C, while CAD Le Marais Rouge was built in 2007, designed and working with much lower supply/return temperatures around 80°C/40°C. Both cases studies supply mostly non-renovated buildings from the 20th century, but in the case of CAD Le Marais Rouge all the substations have the same architecture, that was specifically designed to achieve the lowest possible return temperatures.

Therefore, in comparison to CAD-SIG which is an example of a big historical urban heat network in Switzerland, CAD Le Marais Rouge could be seen as a "best case" example of new generation DHN and potentially also as a target or solution to the old DH systems retrofit.

3.1 CAD-SIG

The CAD-SIG heating network is located on the right bank of the Rhône River in the canton of Geneva, extends over the communes of Vernier, Grand-Saconnex, Meyrin and Ville de Genève (cf. Figure 10). CAD-SIG DHN delivered 359 GWh of heat to 214 substations in 2021. The length of CAD-SIG is 48.4 km, it linear heat density reaches 7.4 MWh/linear meter/year. It is currently owned by the Services industriels de Genève (SIG), an autonomous public law institution entirely owned by the State of Geneva and Geneva's municipalities.

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[1] CAD-SIG and CAD Le Marais-Rouge are the official names of the studied district heating systems

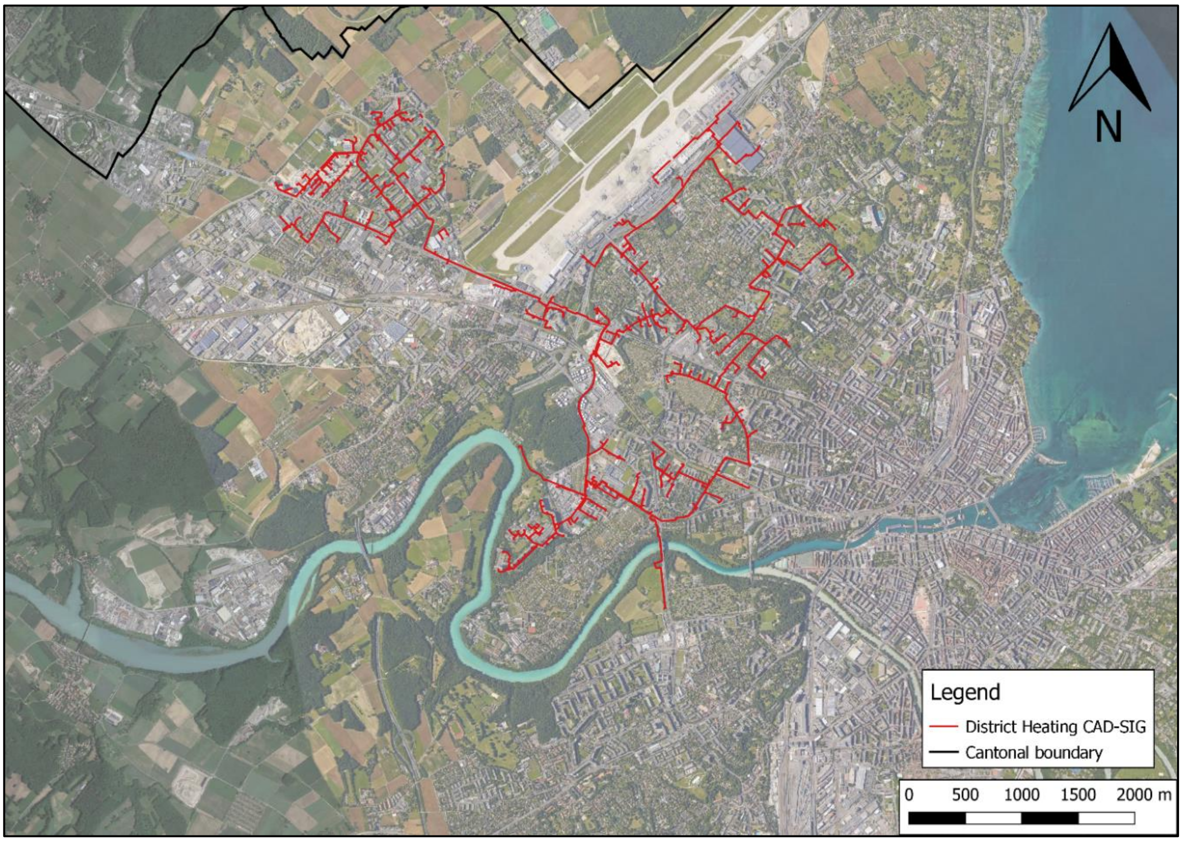

Figure 10 - Graphic representation of the CAD-GIS network in Geneva.

This network was put into service in 1964 to make use of excess heat from a factory producing town gas. It was initially heating the Lignon housing estate, and then progressively extended to other neighbourhoods built nearby in the 1970's (Les Libellules, Les Avanchets). The extension of the network has continued over the last decade (Meyrin in 2010, Vieusseux in 2012). Thus, the types of buildings connected are diverse, ranging from residential buildings built in the 1960's that have not been retrofitted to new buildings, as well as business premises (shops, offices, schools, etc.) [4].

In 2012, the CAD-SIG network was interconnected to the CADIOM network (left side of the Rhone River) distributing heat from the Cheneviers waste treatment and recovery plant, with the aim of recovering an additional part of the excess waste heat available from this plant in summer and mid-season. The CADIOM network is not part of the scope of this study, but supplies part of the CADSIG network, and vice versa to a lesser extent (peak load, backup).

The CAD-SIG network is made up of two tubes (supply & return flow) in pre-insulated rigid materials. It has a centralized main boiler room and several decentralized back-up boiler. The dimensioning data for the CAD is a maximum temperature of 122°C (superheated water), with pressure PN 25. Figure 11 show the daily heat demand load of CAD-SIG and its supply-return daily temperatures. DHW represents 29% of the delivered heat, and the remaining 71% provides SH [14].

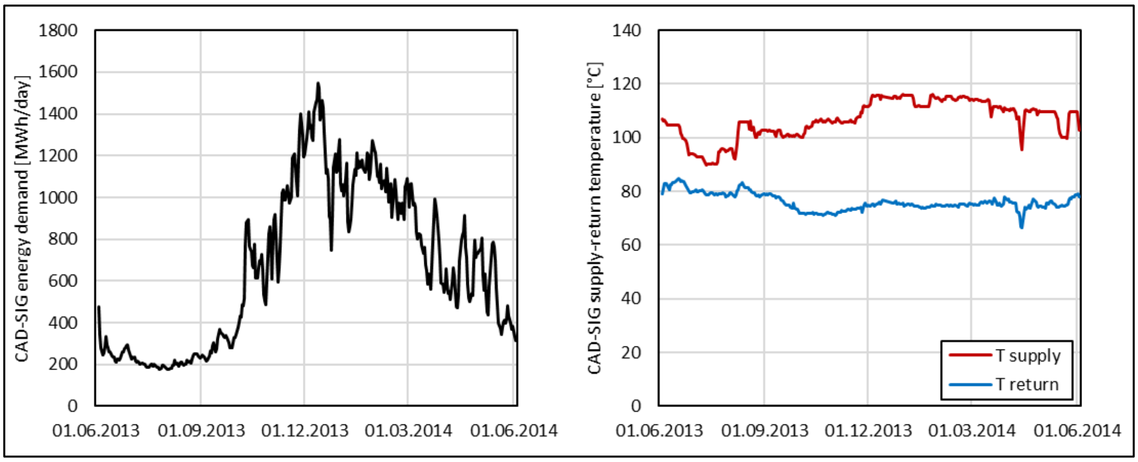

Figure 11 - Daily heat demand load of CAD-SIG (left) and its supply-return daily temperatures (right).

According to the latest data from the Système d'Information du Territoire à Genève (SITG), there are 1’102 number of building alleys (EGID) connected to the CAD-SIG, with a total energy reference area of 3'300’000 m^2. A large majority of these buildings (85%) are of the "collective housing" type, but in terms of energy reference area (ERA) they represent only 65%. The opposite is true for administrative buildings (4%), which represent more than 16% of the total ERA (cf. Figure 12).

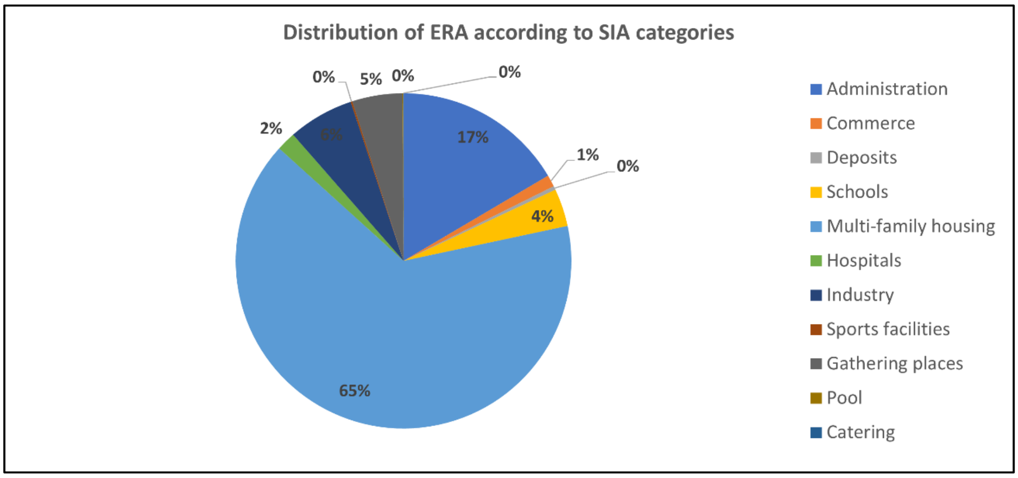

Figure 12 - Percentage of ERA by SIA category. Total ERA = 3'300’000 m^2, 1’102 buildings.

Almost three-quarters of the buildings were constructed during the 1946-1980 period and one in ten buildings was built between 2011 and 2020. Figure 13 illustrates the distribution of ERA by construction period.

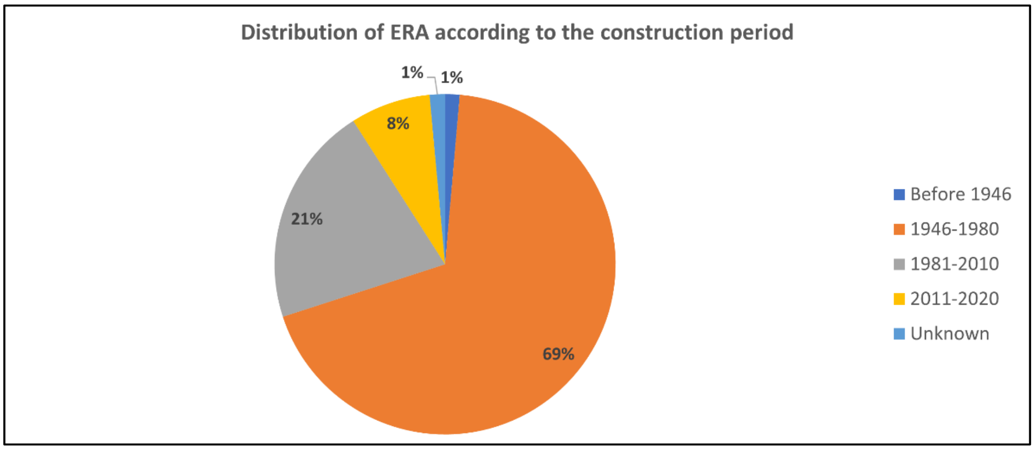

Figure 13 - Percentage of ERA by construction period. Total ERA = 3'300’000 m^2, 1’102 buildings.

The median value of the ERA for all construction periods is about 2'100 m^2. The distribution of the ERA by construction period can be visualized in Appendix 1.

Figure 14 illustrates the usual architecture for the CAD-GIS network substations. It includes a main exchanger on the network (usually owned by the network operator) which feeds the substation circuit (owned by the customer) for SH distribution and DHW production. A motorised valve regulates the primary flow (network side) in the main exchanger according to the distribution temperature required on the secondary side.

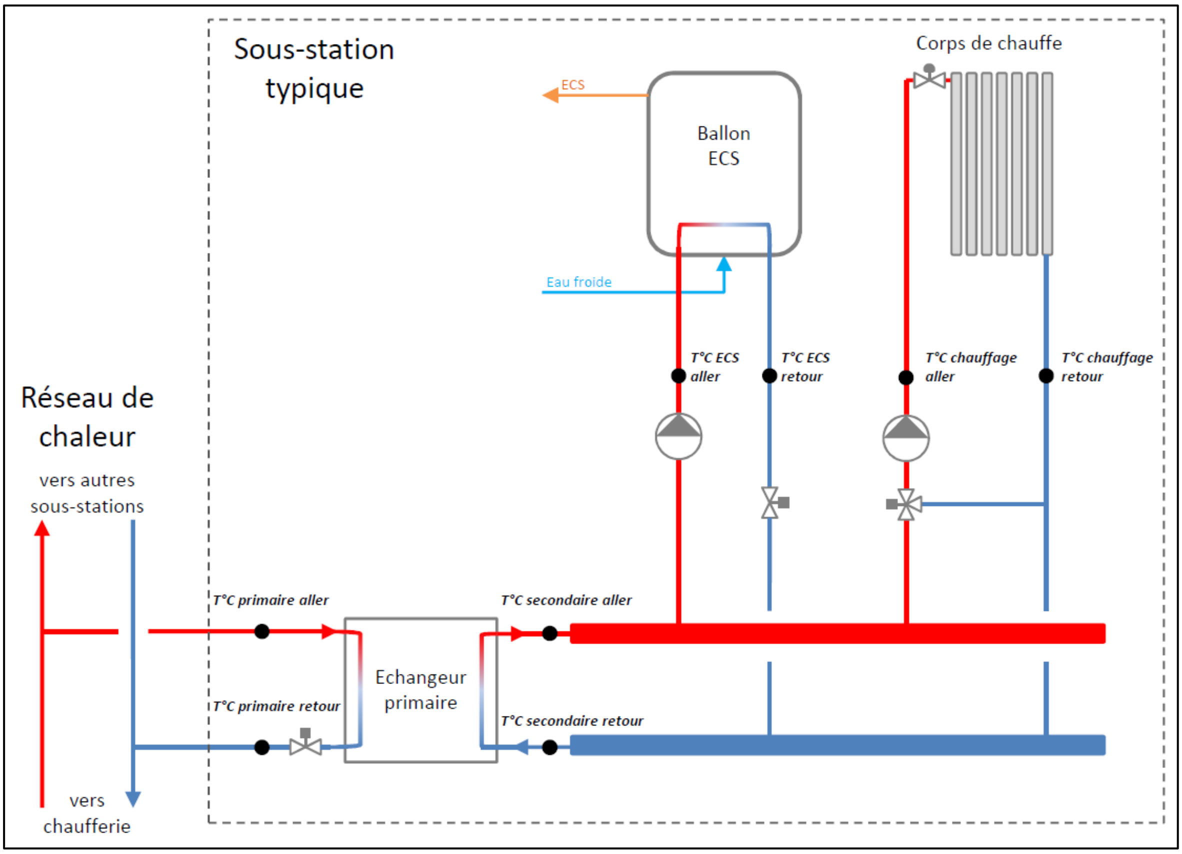

Figure 14 - Usual architecture for substation connected on the district heating network CAD-SIG. Source: [4].

Contracts on CADSIG are generally for 25 years, with a power premium according to the duration of use of the power and a variable part indexed to the price of fuel oil. In total, depending on these factors, the price of heat is approximately between 9 and 14 cts/kWh, of which 3.3 cts/kWh is the fixed part [4].

3.2 CAD Le Marais-Rouge

The DHN "Les-Ponts-de-Martel" entered into operation in September 2007. Initially, 32 buildings in the municipality Les-Ponts-de-Martel were supplied by it for an overall network length of 2.1 km. Ten years later, 87 buildings are connected to the DHN, for a network length of 3.8 km. In 2019, 5.81 GWh were supplied with the network, which represents a linear density of 1.53 MWh/ml/yr.

The whole DHN belongs to a cooperative called "Le Marais-rouge – Société coopérative de chauffage à distance à bois". Each consumer (including potential future consumers) of the network can be part of it society. This special legal status makes of "Les-Ponts-de-Martel" a completely different kind of DHN compared to the system run by heat supply companies. Involving the consumers in a cooperative makes it easier to access secondary heating systems for energy efficiency improvement measures, since they benefit of it: the price per consumed energy depends on the overall efficiency of the DHN.

The DHN is fed by two wood chips boilers, one of 1’000 kW and the other of 1’250 kW (see characteristics in Table 3). An oil-fired boiler is used as backup in case of maintenance or failure of the wood boilers.

Table 3 - Wood boilers characteristics.

Characteristics	**Wood boiler 1: Viessman TMV 17**	**Wood boiler 2: Müller TMV 18TR**
Nominal power (at W 50)	1’000 kW	1’250 kW
Max. Temperature	105°C	110°C
Flowrate	45 m³/h	50 m³/h

The hydraulic diagram of the central heating station is shown in Figure 15. Both boilers are equipped with a smoke condenser (see hydraulic diagram in Figure 15). The two smoke condensers are operated in parallel, preheat the DHN return flow, and operate well if the return temperature is below 50°C. The two wood boilers are operated in series.

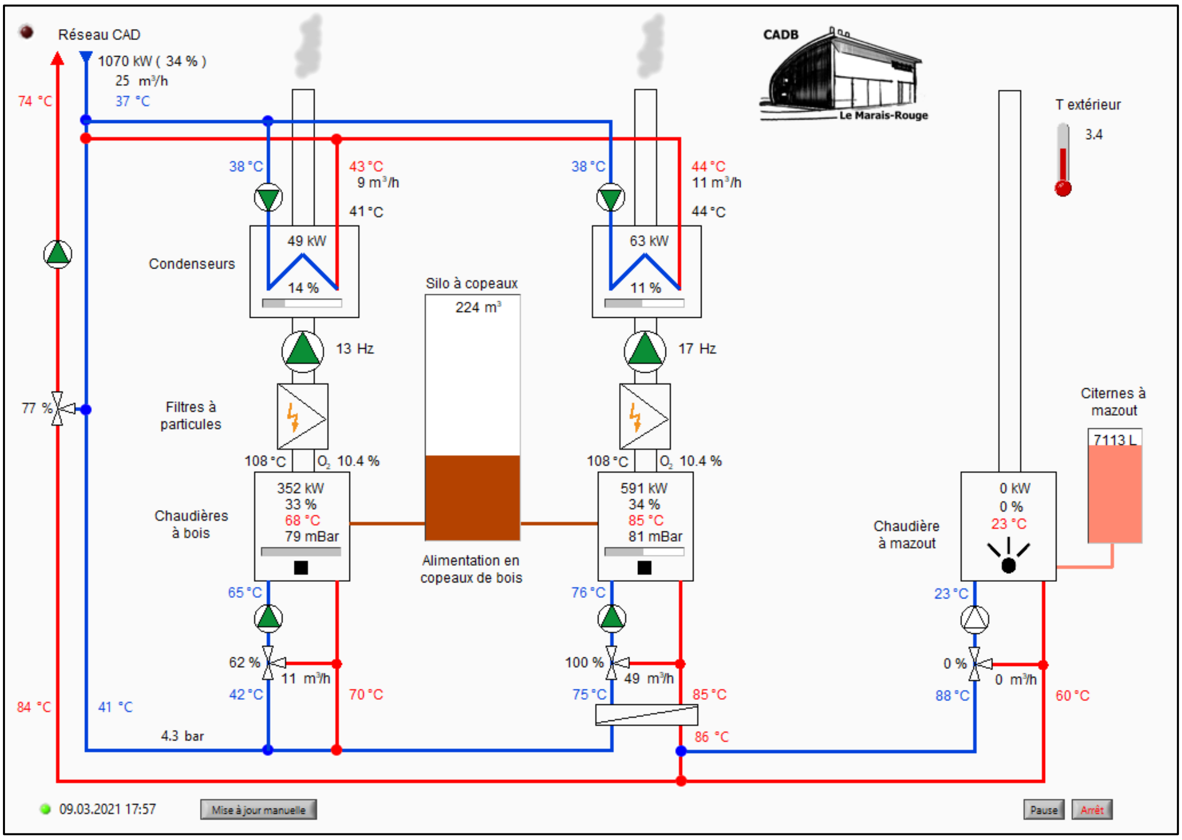

Figure 15 - Central heating station hydraulic diagram.

DHW represents 25% of the total heat demand on the DHN, as estimated by extrapolation of the heat demand outside the SH season, and the remaining 75% covers SH demand. The return temperature fluctuates from 40°C (heating season) to 55°C (summertime, when there is only DHW production). The temperature profile and the monthly distribution of heat consumption are given in Figure 16.

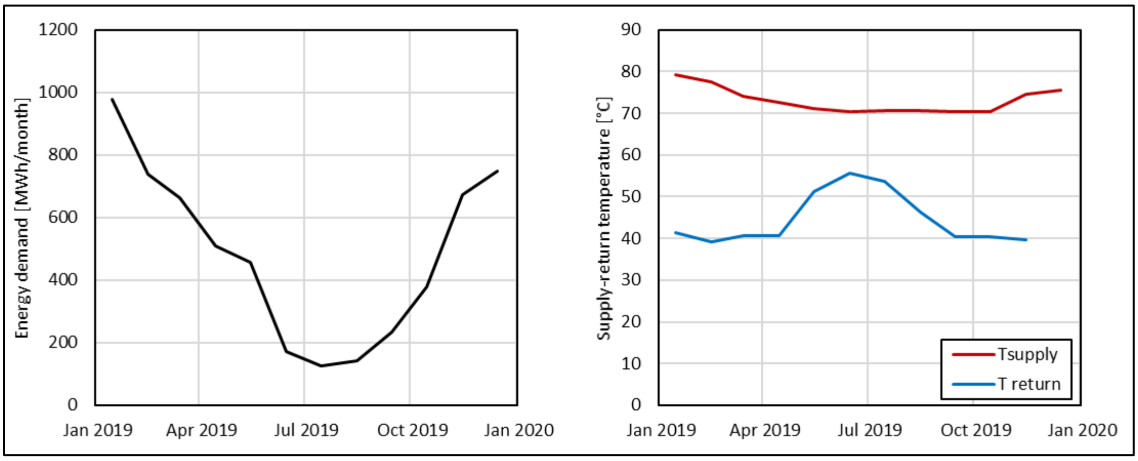

Figure 16 - Monthly heat demand load of CAD Le Marais Rouge (left) and its supply-return temperatures (right).

Among the 87 connected buildings, one can find individual houses, multi-dwelling houses, public buildings (for instance schools, a chapel, etc.) (cf. Figure 17).

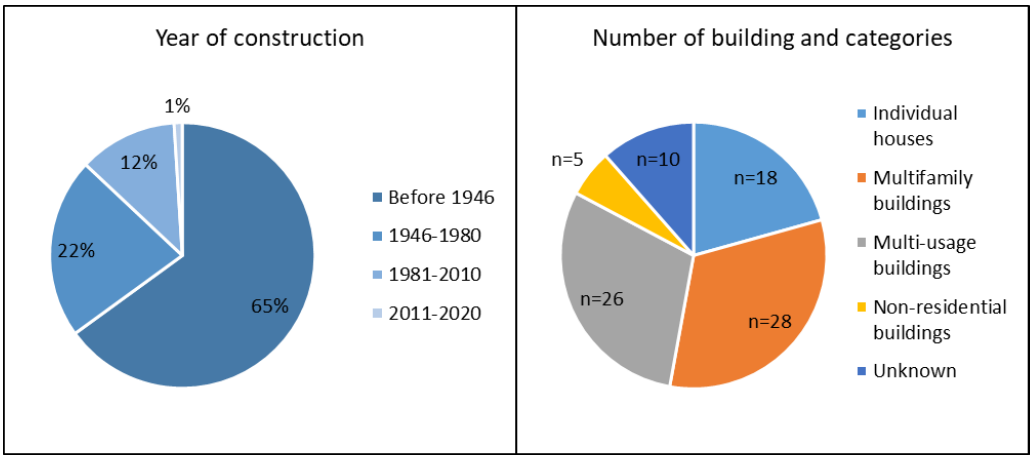

Figure 17 - Characteristics of CAD Le Marais Rouge buildings: year of construction (left) and building categories (right).

The substation architecture used in DHN Le Marais Rouge is relatively innovative in Switzerland. It has been developed in order to (1) minimize the return temperature and (2) to limit the peak power for DHW production. The substation architecture is given in Figure 18.

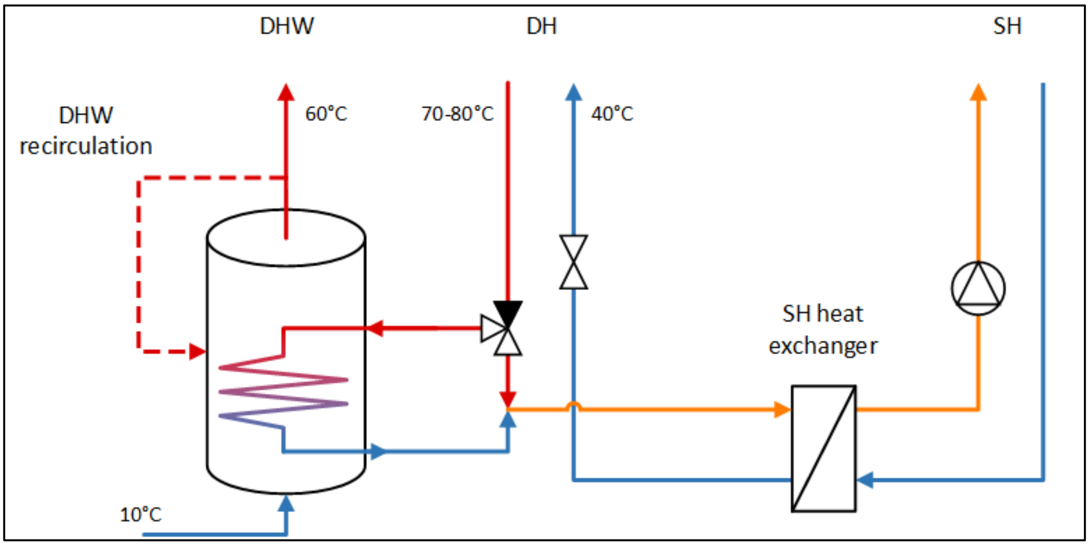

Figure 18 - Substation architecture used in Le Marais Rouge DHN, with two-stage cascade.

DHW is produced directly with the DHN through an immerged heat exchanger. Charging of the DHW tank is regulated through a thermostatic three-way valve. When the temperature in the DHW tank is inferior to the set point, the thermostatic valve opens proportionally and allows water from the DHN to circulate in the immerged heat exchanger. This continuous DHW production limits the peak demand for DWH preparation, and the substation architecture allows to reduce as much as possible the temperature needed to respect the legal legionellae requirements.

Heat for SH demand is exchanged from the outlet of the DHW heat exchanger to the secondary circuit via a plate heat exchanger. The primary flowrate is regulated by a system which takes into account the external temperature, the temperature at the bottom of the DHW tank and the secondary supply temperature. Heat for SH and DHW production can be provided simultaneously.

An important characteristic of this substation architecture is that the DH water for DHW production is further cooled down to provide SH. Thanks to this feature, the primary temperature difference between the supply and return is maximized.

3.3 Cases studies technical characteristics

Table 4 contains the comparative characteristics on key points and technical data for the two case studies.

Table 4 - Summary and comparative table of DHN case studies.

Main characteristics of the two case studies district heating networks		
Name	**CAD-SIG**	**CAD Le Marais-Rouge**
Operator	Services industriels de Genève (SIG)	Société Coopérative Le Marais Rouge
Contact person	Gautier Falize gautier.falize@sig-ge.ch	Didier Barth Didier.Barth@he-arc.ch
Year of construction	1964	2007
Heated area	3'300’000 m^2 (SITG)	NA
Connected population	46'000 people (SITG)	NA
Number of substations	214 substations	87 substations
Reference weather station (SIA2028)	GVE Genève-Cointrin. Annual average 10.9°C	La Chaux-de-Fonds (Western Jura)
Number of degree days (SIA2028-C1 - 20/12°C)	3006	4470
Design temperature	-5°C usually by customers -12°C recommended by SIG	-10°C (SIA2028)
Type of network	2nd to 3rd generation network	4th generation network
Installed power	160 MW gas boilers. 75 MW connection with CADIOM network supplied mainly by the waste heat from Geneva’s household waste incineration plant (60 MW thermal)	2.5 MW wood boilers equipped with flue gas condenser
Subscribed power	206 MW (2021)	3.5 MW

Main characteristics of the two case studies district heating networks		
Supplied energy	359 GWh (2021)	5.81 GWh (2019)
Length of the network trench	48.4 km (2021)	3.8 km
Network architecture	One main centralized heat power plant and several decentralized back-up boilers	One centralized heat power plant
Energy density	7.4 MWh/linear meter/year	1.53 MWh/linear meter/year
Network heat losses	6 % (21.5 GWh)	11.5 % (0.76 GWh)
Supply temperature control	Manual (winter/summer)	Heating curve on external temperature
Supply / return temperature winter	110°C / 70°C (max supply 122°C)	80°C / 40°C
Supply / return temperature summer	100°C / 75-80°C	70°C / 55°C
Supply / return temperature target	90 / 55°C	70°C / 40°C
Heat production mix	71 % natural gas 29 % renewables & waste heat	99 % wood 1 % heating oil
Carbon content of the delivered energy	162 kg CO_2-eq / MWh	44.6 kg CO_2-eq / MWh
Primary energy factor	0.852 MWh oil-eq / MWh	0.154 MWh oil-eq / MWh

4. Ranking of substations with the excess flow method

The objective of this chapter is to explain the methodology used to perform the substation ranking, i.e., the influence of each substation on the DH. Then, it will explain the data available to make this ranking, and finally present the results obtained.

4.1 Methodology

In order to evaluate the operation of the DHN substations, two elements are evaluated for each SST: its primary temperature difference (DHN side) and its influence on the DHN return temperature. For this purpose, the calculations are based on the method proposed by [5]. This method is easily reproducible by the network operator from the indices of the energy meters (heat and volume) of the substations, in particular thanks to the Excel tool developed by Verenum [7]. To detect as early as possible, it would be interesting to perform this analysis frequently, for example on a monthly basis.

Primary temperature difference:

The average primary temperature difference (ΔT) of each SST is calculated using the amount of heat transferred (Q) and the volume of water passed through the substation during a given period (V), as described in equation (1). For this purpose, the simplest way is to use the difference in meter indices of heat and volume of the primary exchanger of the substation, boxed in Figure 14.

Since the index of the volumetric meter was not available among the data transmitted by SIG, the total volume passed through the substation is calculated from the sum of the primary flows ($\sum t\ Vt$), available with a resolution of 10 min. In order for the results to be consistent, the amount of heat delivered is calculated from the sum of the instantaneous powers ($\sum t\ Qt$) corresponding to the flow rates considered, instead of the difference in heat meter indices. If there are data gaps, it is therefore possible that the amount of heat and volume obtained are lower than the actual values, and that the ΔT is not representative of the full year.

$$T_{\mathrm{supply},prim} - T_{\mathrm{return},prim} = \Delta T = \frac{Q}{\mathrm{Cv} \cdot \mathrm{V}} = \frac{\sum \mathrm{t\ Qt}}{\mathrm{Cv} \cdot \sum \mathrm{V}} \qquad (1)$$

where Cv represents the volumetric heat capacity of water.

The target temperature difference ($\Delta Tref$) between the forward and return of a substation is considered to be 45°C, which is a 110°C/65°C supply/return.

Influence on the DHN return temperature:

As illustrated by the example in Figure 19, a non-optimized or faulty SST can have a significant impact on the DHN return temperature.

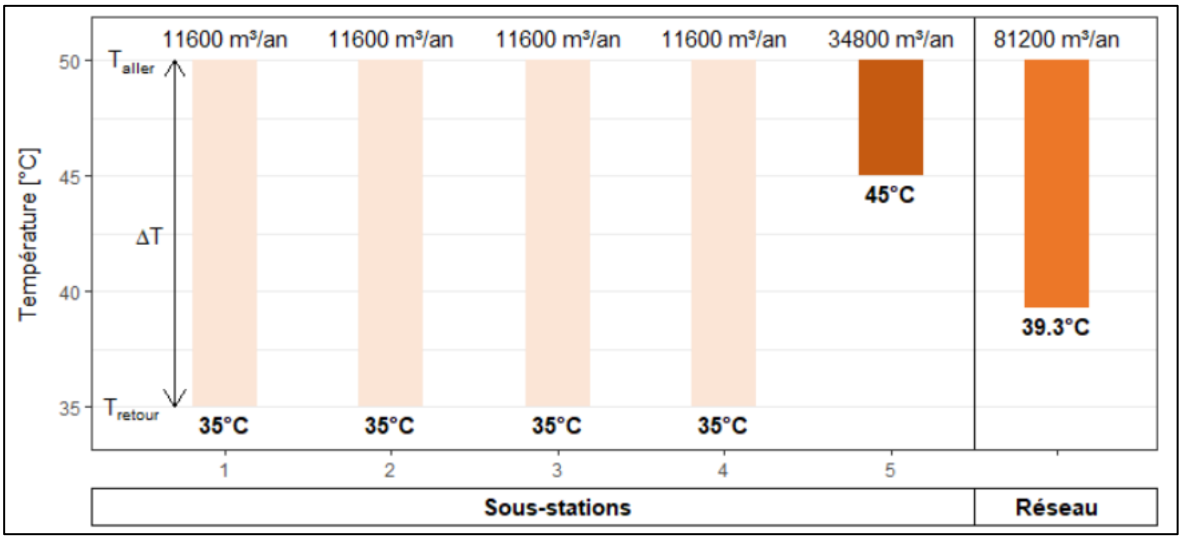

Figure 19 - Example of the influence of a non-optimized substation on the DHN return temperature. The network includes here 5 SSTs with a heat demand of 200 MWh/year each. Source: [12].

In order to evaluate the impact (positive or negative) of this substation on the DHN return temperature, the approach outlined in the "Planning Guide for District Heating" [5] is used. It consists in comparing the DHN return temperature difference in the two situations illustrated in Figure 20, for the same heat demand and leaving the operation of the other SSTs unchanged:

- The measured SST, with average primary ΔT and volume (V) as measured;
- The optimized SST, so that its average primary ΔT is equal to the ΔTref of 45°C. The volume that passes through the SST is then (equation 2):

$$\mathrm{V_{ref}} = \frac{Q}{\Delta\mathrm{Tref} \cdot \mathrm{Cv}} \qquad (2)$$

The impact of optimizing this SST on the total DHN volume is therefore equal to the difference between V and V_{ref}, i.e., the excess volume of this SST over the optimized SST.

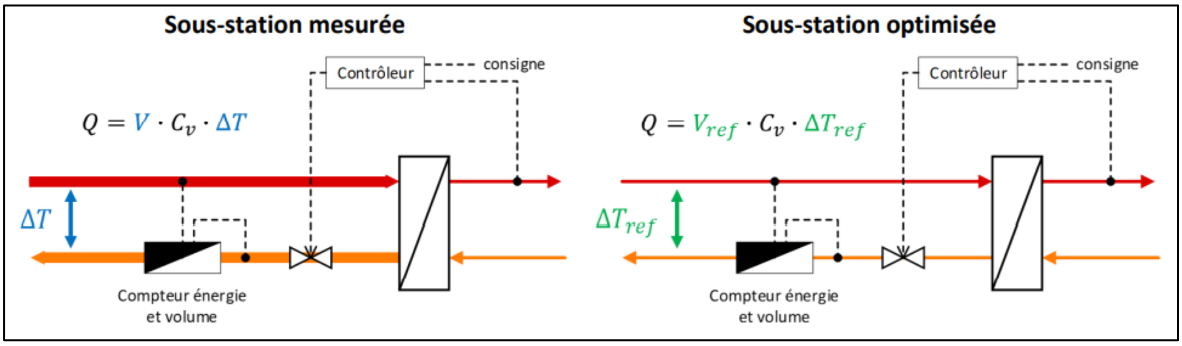

Figure 20 - Comparison between a non-optimized or faulty substation and an optimized substation. Simplified diagram with a single heat exchanger. Source: [12].

For either situation, the DHN supply-return temperature difference is given using the total heat delivered to the SSTs and the total volume passed through them, as described in equation (3):

$$\begin{cases} \Delta T_{CAD} = \dfrac{\sum_{SST} Q_{SST}}{C_v \cdot \sum_{SST} V_{SST}} \\ \Delta T'_{CAD} = \dfrac{\sum_{SST} Q_{SST}}{C_v \cdot (\sum_{SST} V_{SST} - \Delta V')} \; avec \; \Delta V' = V - V_{ref} \end{cases} \quad (3)$$

where ΔV ' represents the excess volume of the SST under study and Cv the volumetric heat capacity of the water.

However, in the case of the CAD-SIG, since the available SSTs data does not represent the entire network, the DHN volume was estimated using SIG data of heat sold on the CAD-SIG network.

Finally, the influence of the non-optimized substation on the DHN return temperature is reflected in the difference between ΔT_{CAD} and $\Delta T'_{CAD}$.

4.2 Data availability

Two categories of data can be distinguished for the evaluation and optimization of substations:

- Basic data: energy & annual volume consumed by each SST, DH side supply & return temperatures;
- Detailed data: energy, volume, temperatures on a monthly or hourly basis (seasonal dynamics); data on the secondary side of the SST (flow-return temperature for SH flow-return temperatures for DHW production, flow rates, set points and regulation operation).

The basic data allows the global follow-up of the substations on a heating network, the detection (with time lag) of temperature errors and the prioritization of the substations on which to intervene. If the SST is prioritized in the DH analysis, but the visit does not show any obvious problems, a detailed data set on the operation of the substation may be necessary to define the origin of the high return temperatures. It may come from the secondary circuit of the SST itself, by example coming from a specific temperature need of the building. As even basic data on substation are not necessarily existing and/or easy to collect, obtaining detailed data on a substation implies additional efforts, contacts with building owners or managers, and even the installation of the necessary sensors.

4.2.1 SST CAD-SIG network

For this study, the Services industriels de Genève (SIG) provided a large amount of telemetry data from 2017 to 2021, in 10-minute time steps. Within this study we use the hourly aggregated data of load, temperature (supply, return) and flow rate.

It is important to note that there are many data gaps in the SIG dataset. Indeed, the basic dataset specifies 151 distinct substations, but 93 of them are empty. Furthermore, for the remaining 58 SST, the quality of the data transmitted varies according to the year. In fact, an SST may have no data available for a specific year and some or all data for another year. The table in Appendix 2 shows the percentage of hourly data available for the years 2017 to 2021 for each of the 58 available SST. Figure 21 provides the number of SST per year that fall within the ranges of data availability. For example, the SSTs in the "70-80%" range have yearly data availability between 70 and 80%. Finally, we note that the year 2021 is the year with the highest data coverage as we have

26 SSTs with >90% coverage and an additional 15 SSTs with coverage between 70 and 90%. Therefore, it is logical that we will use the year 2021 to perform the preliminary analysis.

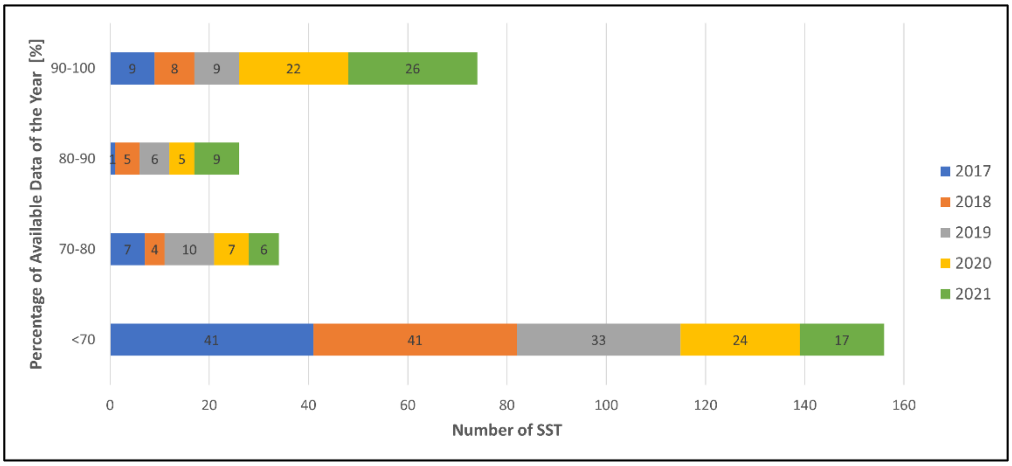

Figure 21 - Distribution of Percentage of Available Data by SST-Year.

4.2.2 SST CAD Le Marais-Rouge network

For the Marais-Rouge the following data are currently available from the DH network operator:

1. More than 50 points of measurements on central heating station collected on an hourly basis;
2. Data available from each substation from 2007 until 2021 at monthly frequency: kWh-oe heat consumed per month, monthly volume consumption, monthly maximum temperature, average temperature difference.

In addition, it could be possible to:

1. Increase the rate of data sampling (one point per minute) for one substation, for several weeks, in order to better understand the substation dynamic;
2. Collect the SH curve parameters for each building (to be checked with the DHN operator).

4.3 Ranking of CAD-SIG substations

The preliminary analysis presented here concerns the 26 SSTs for which the year 2021 is at least 90% covered. For the excess flow method, we used the total heat delivery of 359 GWh from which we derived a total volumetric flow of 8 million m^3.

Preliminary results show that most SSTs have a ΔT lower than 45°C (SIG objective) since their volumes are quite often in excess. Indeed, as shown in Figure 22, only 7 SSTs (27%) out of the 26 reach or are above the SIG objective. This situation is not only present for the year 2021, since in 2020 only 29% of the SSTs reach the objective, 26% in 2019, 19% in 2018 and 29% in 2017 (see Annex 3).

Not surprisingly, the SSTs with the highest heat demands are also the ones that have the most impact on the CAD-SIG return temperature. In Figure 22, we notice that the two SSTs (n°15 and 29) with the highest heat demand are also those with the largest excess flow (more than 30'000 m^3). These are therefore the priority SSTs to be analyzed in more detail by the network operator. Paradoxically, it may be more interesting for the network operator to optimize the SSTs with the highest heat demand (with return temperatures close to the target), rather than the small SSTs with catastrophic return temperatures.

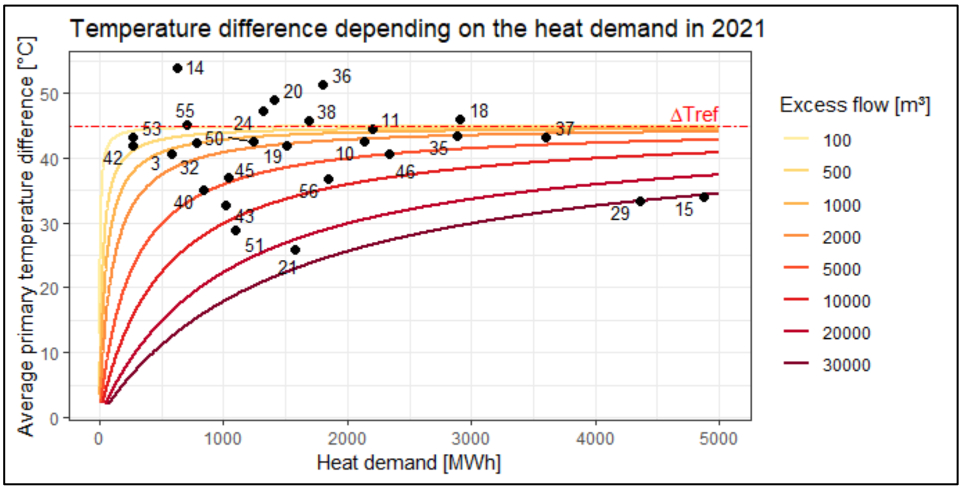

Figure 22 - Impact of SST on the return temperature of the CAD-SIG in 2021.

These excess flow values indicate a substation malfunction. This may be due to a faulty component or a major control problem (on the primary or secondary side).

4.4 Ranking of CAD Le Marais-Rouge substations

Available data from Le Marais Rouge DH network was used to rank the efficiency of each substation following the same methodology used for the CAD-SIG. To perform this analysis, the total monthly volume consumed per substation and the amount of heat billed to the substation each month were used.

Figure 23 (a) shows that most of the substation have a yearly average temperature difference above 35°C. Knowing the maximum supply temperature of 80°C, this means that the return temperature for those substations is around 40-45°C, low enough to allow for water condensation in flue gas.

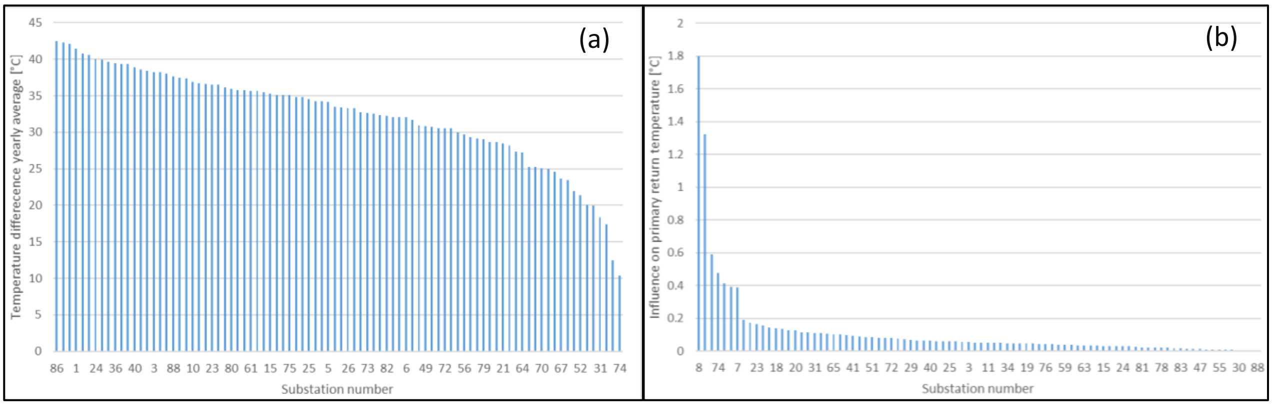

Figure 23 – (a) Average temperature difference by substation and (b) impact on the global temperature difference of each substation with a targeted temperature difference of 45°C.

Figure 23 (b) allows to identify the most critical substation to reach the 45°C temperature difference target. This Figure shows that the optimization of the five most impacting substations could potentially improve the temperature difference by almost 5°C. Figure 23 (b) allows also to identifying the most problematic substation. The two worst substations could improve the DHN global temperature difference by 1.8 and 1.3°C respectively. These two substations correspond to building with particular function: the first one is a retirement home and the second one corresponds to a train maintenance workshop. A visit will be organized to those two substations in order to identify the potential measures which could increase the average temperature differences.

5. Visit of substations

We carried out visits of substations of the SIG network to gather information on their architecture, components, clarify connected buildings, and in order to pre-identify potential sources of high return temperatures on DHN. Substations visits were also needed in preparation of complementary monitoring and data acquisition for further detailed analysis planned in DeCarbCH WP 7 tasks.

5.1 Checklist for the visit and audit of substations

We present hereafter two lists we developed for the visit and audit of the substations concerning their influence on the return temperature of the heating network.

The "roadmap for substation visit" is a list of useful items or information to observe or collect during a first visit to a substation, in order to get an idea of its functioning, its main characteristics. This roadmap for substation visit could serve as information source in order to later complete the auditing checklist.

The "auditing checklist" is designed to obtain a synthetic qualitative analysis of a substation with respect to key points in terms of return temperatures on the DHN. It can be used to define a possible need for additional data in order to achieve the substation analysis and temperature errors determination. To prioritize the substations to be visited, this field work should be done after a ranking and selection of the least efficient substations based their weighted average temperature difference on the DHN. These lists are not exhaustive and can be modified later according to the findings in the field.

5.1.1 Roadmap for substation visit

List of useful information to be collected during a substation visit:

Building:

- Name / ID of substation, date of visit & who is doing the visit;
- Address, access to sub-station;
- Building manager, heating engineer, building caretaker;
- Type of building: SIA category, year of construction, heated area, heat utilization index;
- Type of heat emitters: radiators, floor heating.

Hydraulics:

- Schematic diagram of the SST (exchangers, power, outlets, etc.);
- Identification of the aisles/buildings connected to the substation;
- Power and model of primary heat exchanger CAD, connection (ideal counterflow);
- Number of SH sector and DHW preparation outlets, type of regulation (3-way valve);
- Information on secondary exchangers (sub network, SH distribution, DHW preparation);
- Type of SST architecture for DHW production and SH distribution (series or parallel heat exchangers, try to classify the SST according to substation architectures depicted by Sven Werner);
- DHW storage tank: architecture of connections if multiple tanks (series or parallel connection), functional analysis, size of DHW tanks, cold water connection, return of DHW circulation;
- Decentralised storage tanks in the aisles/buildings.

Metering:

- Heat metering: type of flow meter, metering range, scope of measurement;
- Measuring points, temperature sensors (SH, DHW);
- Automatic controllers: type of technology, model, data accessibility.

Other:

- Comments or observations.

5.1.2 Auditing checklist

Positive answers to these questions indicate points of vigilance in terms of substation return temperatures on the DHN.

Building:

- Old building?
- Old substation (more than 10 years old)?
- Has the substation replaced an older heat production system (fossil boiler)?
- Presence of several heated buildings by the same substation?

Hydraulics:

- Does the substation supply a secondary heating network?
- Space heating: presence of exchangers in series from the primary exchanger?
- DHW: Are there exchangers in series with the primary exchanger?
- DHW production with internal exchanger?
- Presence of bypass in the substation (on collectors)?
- Presence of 3-way valves:
    - on secondary circuit?
    - on SH outlets?
    - on DHW outlets?
- Presence of DHW storage?
- Presence of multiple stocks?
- Presence of decentralized DHW storage in the aisles?
- Local heat production installation (fossil, renewable, waste heat)?
- Production or preheating of DHW or SH (solar thermal, heat pump)?

Metering:

- Problems with the temperature sensors of the heat meters?
- Inconsistency in the substation temperature settings (heat curve, temperature needs on the secondary side of the substation)?

5.2 Example of visit to a substation

5.2.1 Analysis of available data

With the intention of applying the methodology described in the chapter 5.1.1, a visit to a CAD-SIG substation was conducted; this could be called pre-auditing. For this purpose, we selected a substation with a significant impact on the DHN return temperatures and with good data quality. Using the preliminary results (cf. chapter 4.3 Ranking of CAD-SIG substations) we selected the worst substation (SST n°15) - with a high thermal demand and a ΔT below the SIG target (45°C). Once this selection was made, additional work had to be done, as the data provided by SIG does not allow us to know which buildings are connected to each substation. This additional work consisted in creating a link between the substation and the buildings probably connected using several georeferenced layers found on the Système d'Information du Territoire à Genève (SITG). This linkage was done through the heat expenditure index and the geographical location. The heat expenditure index is an indicator of the energy consumption of a building to cover its heating needs (SH and DHW). It represents the annual quantity of final energy consumed for heat production, reduced to one square meter of heated floor (ERA) and corrected according to the climatic data of the considered year. Table 5 summarizes the basic information of the buildings connected to the visited substation n°15. It should be noted that 56% of the ERA is allocated to collective housing buildings, and the remaining 44% comes from collective housing buildings with activity on the first floor.

Table 5 -Information about the buildings connected to substation n°15 in 2020.

Period of construction	Alleys		ERA		Heat Demand 2020	
	Number of EGID	[%]	[m^2]	[%]	[MWh]	[kWh/m^2]
1946 – 1980	8	31 %	16’953	44 %	1’953	115.2
1981 – 2010	18	69 %	21’588	56 %	2’378	110.2
Total	*26*	*100 %*	*38’541*	*100 %*	*4’331*	*112.4*

Figure 24 shows the load curve between 2017 and 2022 for this substation.

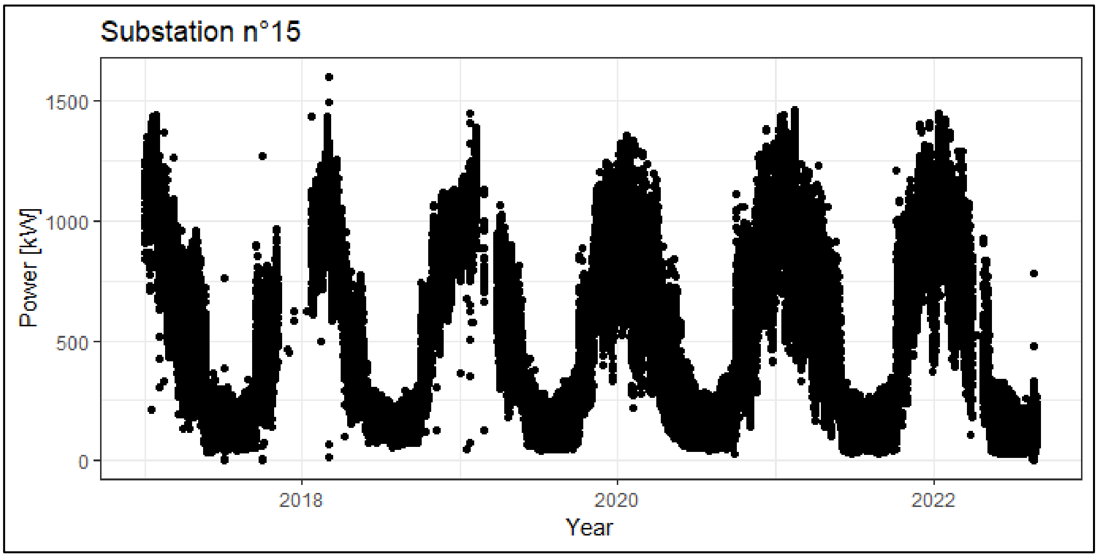

Figure 24 - Hourly load curve of the substation with the highest excess flow in 2021.

Over the entire five-year period (2017 to 2021), nearly 84% of the hours have measured data. This percentage even rises to 99.9% in 2020 and 2021. As shown in Figure 25, the average temperature difference is systematically below the 45°C target set by SIG. This situation is even worse in summer since the ΔT is below 25°C. This is due to the fact that the DHN is only used to meet the thermal needs of the DHW (higher temperature). However, in all likelihood, the system must not be very efficient in meeting the DHW needs because with an average flow temperature around 100°C, it is not normal that the temperature difference is so low. Moreover, we can also see the different flow temperature plateaus that come from the regulation of the CAD-SIG network itself.

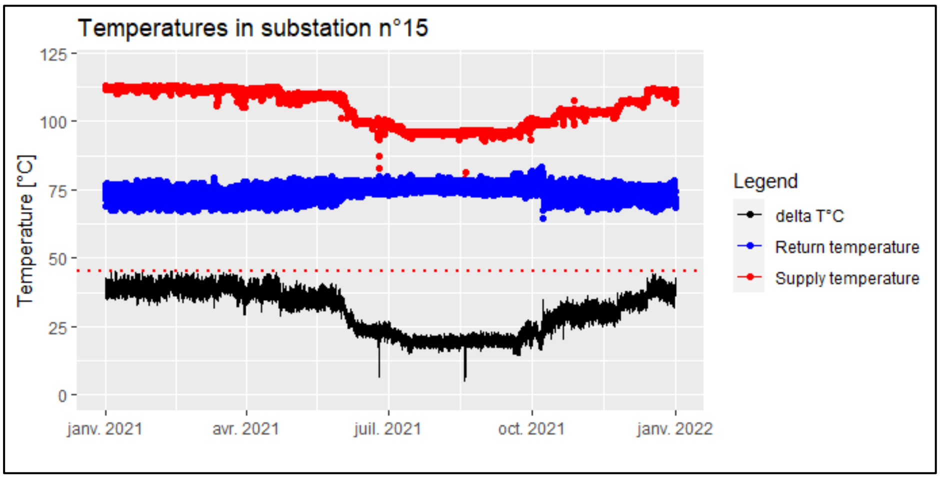

Figure 25 – Temperature of supply and return for the year 2021.

5.2.2 Visit of the substation

The visit was carried out by following the checklist created and presented previously. This visit allowed us to increase our knowledge on the reality of the operation of substation n°15, namely the fact that it actually feeds a secondary neighbourhood network, which is prior to the construction of CAD-SIG (cf. Figure 26).

Figure 26 - Main substation feeding an old district heating of neighborhood.

The fact that this substation does not only supply one building means that there are additional heat exchangers in series; two for SH and three for DHW production. We have seen that this is a typical situation where the CAD-SIG has replaced fossil boilers (in this case oil-fired) that used to supply a private DHN of neighbourhood for a group of buildings belonging to the same owner. The site visits also revealed other potential problems, such as:

- use of the DH circulation pumps, which appear to be old, probably with a fixed flow rate;

- presence of a manifold on the SH outlets with a partially open bypass (return of part of the hot flow directly to the substation exchanger) (cf. Figure 27);

Figure 27 - Manifold with partially open bypass on the right.

- presence of two DHW storage tanks with production by internal exchangers (characteristics unknown). Operation of the load and the withdrawal undetermined, but a priori, operation in parallel (cf. Figure 28);

Figure 28 - Two stocks of DHW production with internal exchangers.

- presence of heat meters on SH and DHW production outlets. It would therefore probably be possible to obtain more detailed data;
- the situation is still uncertain with respect to the other buildings connected to this substation because we were not able to visit the boiler rooms of these buildings. However, a meter on the secondary DH outlet is present but complicated reading because located on the ceiling at three meters from the ground.

These different observations made *in situ* allow us to affirm that this is indeed a priority substation, but that it will be complex to optimize it and that to do so, it is necessary to look further into the different points raised. Significant technical, financial, and human resources will have to be put in place to really improve this substation. It might therefore be useful to develop an additional indicator (based on cost-benefit), which would take into account the difficulty to realize temperature optimization of a specific SST. Indeed, perhaps substations considered as non-priority (because low impact on the ΔT) would be interesting to treat if the improvement is extremely easy to obtain and cheap.

6. Conclusion

In this delivery we describe two district heating networks (DHN) selected as cases studies on the topic of temperature reduction in existing district heating (DH) substations.

The first one is CAD-SIG in Geneva (GE), one of the main DHN in Switzerland, built and extended since the 1960's and delivering 359 GWh/year of heat. The second one is CAD Le Marais Rouge in les Ponts de Martel (NE), deployed in 2007 and supplying 6 GWh/year of heat. Both are supplying heat mostly to existing residential buildings from the 20th century, but their temperature levels are quite different. The supply/return temperatures in winter reaches typically 110/70°C for CAD-SIG, while they are 80/40°C in CAD Le Marais Rouge. The latter are made possible by the initial choice of a single cascaded architecture for all substations in this network and by optimization work carried out on the secondary circuits of the substations.

Among other advantages, decreasing working temperatures of DH will facilitate renewable and waste heat integration, and therefore help to lower the carbon content of DH systems, a key component for the energy transition.

In order to achieve lower temperatures in existing DH systems, the first step is to detect temperature errors and prioritize interventions between substations. The excess flow method seems to be the most common and easy tool to do so, based on each substation's energy and volume use data on an annual basis, ideally monthly. It allows ranking all the substations by their influence on the primary return temperature.

Once the problematic substations are selected, we provide visiting and auditing checklists to gather useful information and look for the most obvious temperature errors sources in substations. Detailed substation data as complementary monitoring may be needed to understand and resolve temperature errors if they are not obvious.

According to the literature, the majority of errors are due to setpoint and control problems as well as problems with components in the secondary circuit of substations. This second point is delicate, as in most cases the secondary part of the substation is owned and operated by the customer.

Finally, based on the excess flow method, we ranked the substations on the CAD-SIG network and selected one with a lower primary temperature difference than expected and a high energy use, and therefore to improve as a priority. Then we visited it, using and testing our visit and auditing checklists, and found several elements that may cause high primary return temperatures (and therefore low primary temperature difference).

The next steps of our work in DecarbCH Task 7.1 *Temperature reduction in existing DH substations* will include the continuation of the visits of the selected (prioritized) substations on CAD-SIG, complementary monitoring, understanding and analysis of their operation and identification of the elements at the origin of high return temperatures on the DH network. We aim to propose one or two solutions for temperature reduction in selected substations and build a model of the selected solutions to characterize potential improvements. As a complement, we will perform detailed monitoring of 1-2 SST of CAD Marais Rouge, for calibration/validation of an existing numerical model (Trnsys). Latter will be used for assessment of the potential of such a SST architecture on SSTs of CAD-SIG.

7. References

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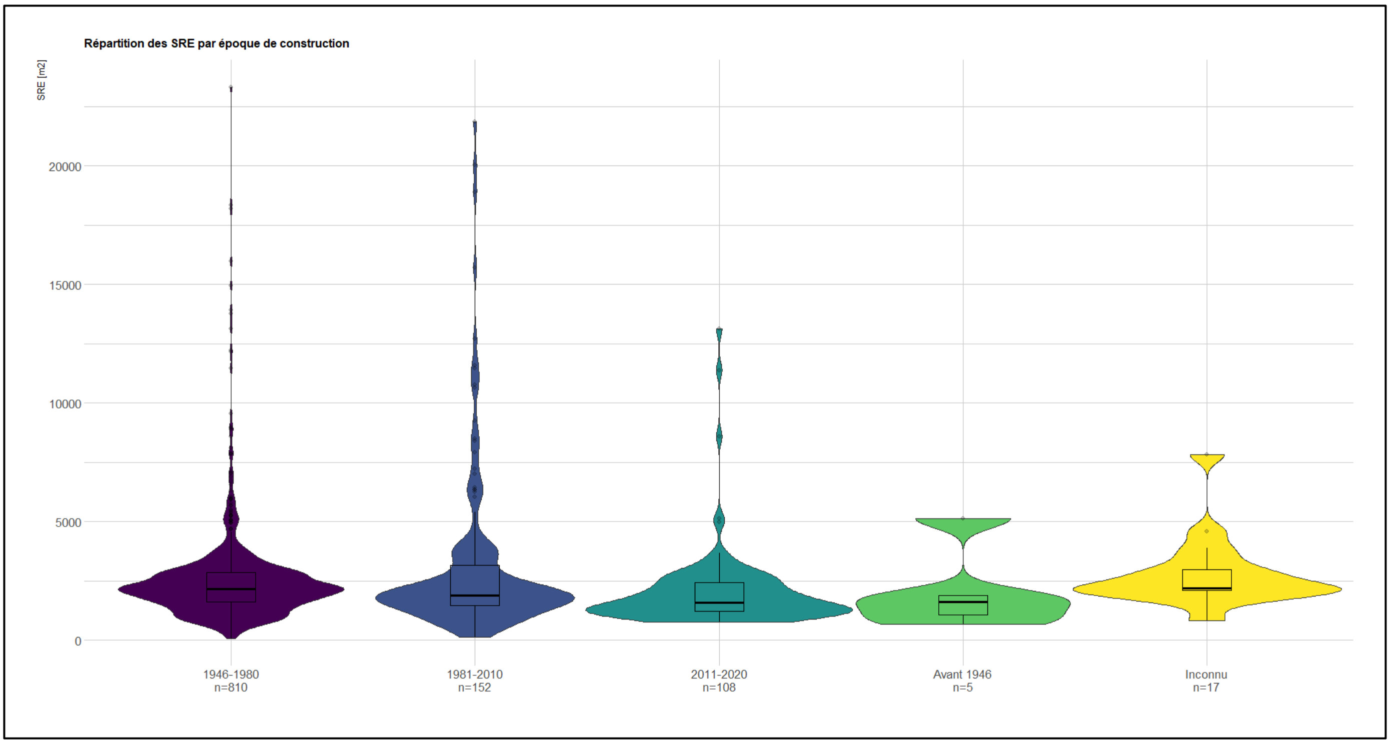
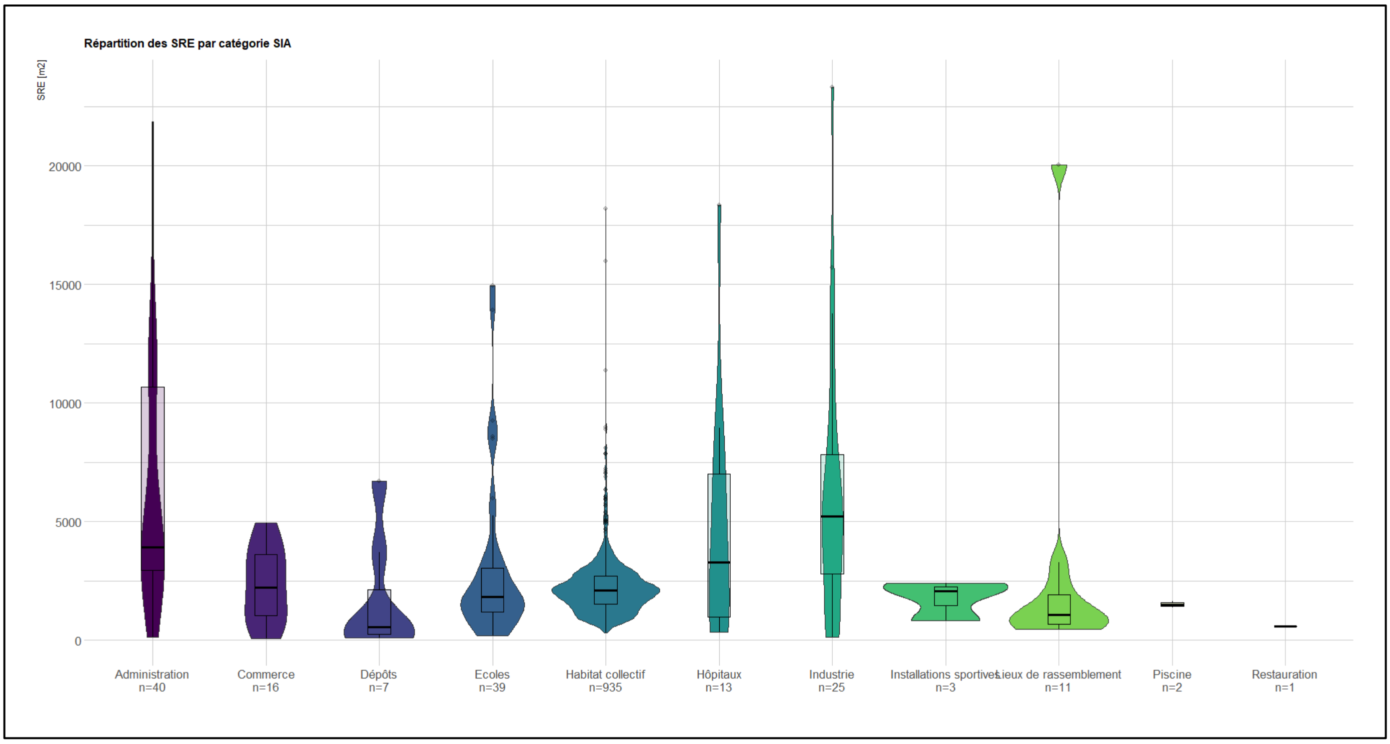
APPENDICES

Appendix 1 – Distribution of ERA and number of buildings of SIG DH network

Appendix 2 – Table of the percentage of year with available data of SIG DH network

Appendix 1 – Distribution of ERA and number of buildings of SIG DH network





These graphs do not take into consideration the ten largest buildings (out of 1'102) in terms of ERA

Catégorie SIA	**SRE [m^2]**	**%**	**Nbre bâtiments**	**%**
Administration	546 071	16,5%	46	4,2%
Commerce	37 533	1,1%	16	1,5%
Dépôts	12 146	0,4%	7	0,6%
Ecoles	120 231	3,6%	39	3,5%
Habitat collectif	2 151 327	65,1%	936	84,9%
Hôpitaux	61 383	1,9%	13	1,2%
Industrie	209 133	6,3%	26	2,4%
Installations sportives	5 327	0,2%	3	0,3%
Lieux de rassemblement	159 917	4,8%	13	1,2%
Piscine	3 003	0,1%	2	0,2%
Restauration	589	0,0%	1	0,1%
Total	**3 306 660**	**100%**	**1 102**	**100%**

Période de construction	**SRE [m^2]**	**%**	**Nbre bâtiments**	**%**
Avant 1946	45 532	1,4%	6	0,5%
1946-1980	2 269 394	68,6%	813	73,8%
1981-2010	692 565	20,9%	157	14,2%
2011-2020	251 072	7,6%	109	9,9%
Inconnu	48 097	1,5%	17	1,5%
Total	**3 306 660**	**100%**	**1 102**	**100%**

Appendix 1

Appendix 2 – Table of the percentage of year with available data of SIG DH network

SST_ID (anonymized)	% Year				
	2017	2018	2019	2020	2021
1	-	-	-	20,2	42,3
2	-	-	-	3,9	-
3	73,2	92,6	90,9	95,3	92,3
4	99,8	92,5	85,1	95,1	85,4
5	-	-	33,0	92,5	89,2
6	-	-	4,0	2,9	13,9
7	-	-	21,0	27,4	38,1
8	-	-	-	56,9	54,3
9	-	-	-	50,8	89,1
10	65,5	79,9	92,6	99,9	99,9
11	73,7	72,3	89,3	99,9	91,7
12	-	-	66,0	72,8	71,9
13	-	-	76,2	81,6	76,3
14	99,9	82,3	44,9	76,8	94,4
15	84,2	89,0	80,4	99,9	99,9
16	-	-	-	78,8	82,1
17	-	-	0,2	62,9	43,0
18	-	-	50,6	99,9	99,9
19	35,4	90,7	92,6	91,2	99,8
20	-	-	73,0	99,3	99,8
21	-	-	73,0	99,1	99,9
22	-	-	73,0	92,4	87,9
23	-	-	59,3	81,8	78,9
24	-	-	72,8	98,8	98,9
25	-	-	44,9	-	51,4
26	-	-	-	2,8	-
27	74,2	64,6	70,0	73,6	80,7
28	-	-	-	-	51,0
29	76,2	72,9	92,6	99,9	99,9
30	78,5	65,3	72,9	63,2	75,6
31	55,7	37,0	-	-	72,1
32	92,1	56,3	92,0	99,4	99,4
33	94,4	90,0	77,7	58,8	70,2
34	91,4	82,0	88,7	81,1	88,3
35	66,2	72,6	92,6	92,1	99,9
36	100,0	94,6	89,7	99,9	94,3
37	78,0	90,7	92,6	99,9	99,9

SST_ID (anonymized)	% Year				
	2017	2018	2019	2020	2021
38	15,0	6,2	88,2	99,9	91,4
39	94,3	82,3	-	-	59,6
40	-	-	-	37,0	99,9
41	-	-	43,4	68,2	68,8
42	-	-	52,4	79,0	96,7
43	-	-	-	59,4	99,8
44	55,5	51,5	51,2	68,1	67,7
45	-	-	-	6,5	99,9
46	94,8	94,7	92,6	99,9	99,9
47	77,9	90,6	79,4	72,6	88,2
48	-	-	-	13,7	60,3
49	-	20,8	56,7	59,7	39,6
50	-	-	32,6	89,7	92,5
51	-	-	51,6	97,5	93,8
52	49,6	51,3	-	8,1	42,7
53	-	-	67,1	92,7	96,7
54	-	8,0	56,6	89,5	88,5
55	95,0	94,1	92,5	99,9	93,8
56	-	-	73,1	74,8	99,7
57	-	-	-	-	26,8
58	-	-	-	-	31,7