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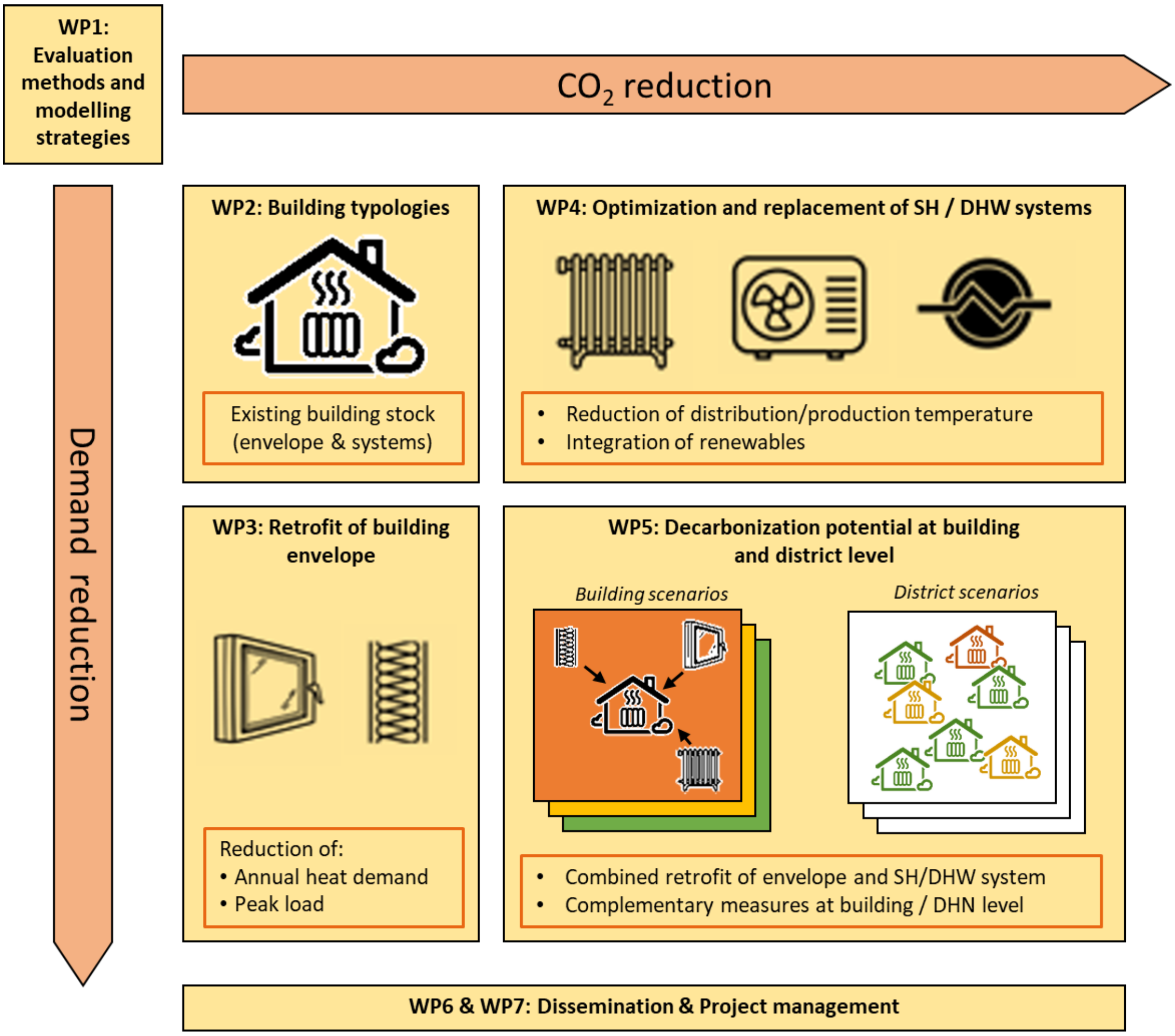
T-DROP

Lowering of heat distribution temperatures, for integration of renewables and decarbonization of multifamily buildings in dense districts



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Zusammenfassung

Als Voraussetzung für die massive Integration erneuerbarer Energien und die Dekarbonisierung mithilfe von Wärmepumpen oder Fernwärme untersucht das Projekt T-DROP optimale Kombinationen aus gezielter Renovierung der Gebäudehülle und technischer Optimierung von Wärmeverteilungssystemen, um die Verteilungstemperaturen zu senken. Der Schwerpunkt bezieht sich auf Mehrfamilienhäusern in dicht bebauten Stadtvierteln. Ein breites Spektrum von Fallstudien mit unterschiedlichen Gebäudetypologien wird genutzt, um Archetypen von Gebäuden und Systemen zu charakterisieren, prospektive Szenarien zu testen sowie die gewonnen Empfehlungen auf nationaler Ebene umzusetzen.

Résumé

Comme préalable à l'intégration massive d’énergies renouvelables et à la décarbonation à l'aide de pompes à chaleur ou de chauffage urbain, le projet T-DROP explore les combinaisons optimales de rénovation ciblée de l'enveloppe et d'optimisation technique de systèmes de distribution de chaleur, pour en abaisser les températures. L'accent est mis sur les bâtiments multifamiliaux dans les quartiers denses. Un large éventail d'études de cas, avec des typologies de bâtiments diverses et variées, sera utilisé pour caractériser les archétypes de bâtiments et de systèmes, pour tester des scénarios prospectifs, ainsi que pour transposer les recommandations au niveau national.

Summary

As a requisite for massive integration of renewables and decarbonization with heat pumps or district heating, the T-DROP project explores optimal combinations of targeted envelope retrofit and technical optimization of heat distribution systems to lower its temperatures. Focus is set on multifamily buildings in dense districts. An extensive set of case studies, with diverse and mixed building typologies, will be used for characterization of building and system archetypes, for testing of prospective scenarios, as well as for disseminating recommendations at national level.

Contents

Abbreviations

DHN	District heating network
DHW	Domestic hot water
HEX	Heat exchanger
HP	Heat pump
KPI	Key performance indicator
MFB	Multifamily building
P&D	Pilot and demonstration
SH	Space heating
SST	Substation

1 Introduction

1.1 Background information and current situation

Buildings account for around 45% of Switzerland's final energy consumption and 33% of its CO_2 emissions [1], representing one of the most important sectors for massive decarbonization. Approximately 70% of their final energy consumption is related to space heating (SH) and domestic hot water (DHW), and 55% of all buildings are still heated with individual fossil fuel boilers [2]. Finally, 80% of them have an area-specific heating demand which exceeds the current minimum energy performance value for new constructions, 40% of them reaching more than twice this threshold. This points out to the need of massive and efficient retrofit of the existing building stock, with combined switch from fossil fueled boilers to renewable energy systems [3].

A specific issue concerns multifamily buildings (MFBs) which represent about 55% of the residential heated floor area at national level, but up to 80% in urban Cantons like Basel or Geneva [3], [4]. Especially in dense urban areas, district heating networks (DHNs) or air-source heat pumps (HPs) often turns out to be the only available option for replacing fossil fuel boilers, since other renewable energy sources are often limited [5]: prohibition of wood boilers in areas with excessive emissions; limitation of solar energy resource due to roof size and patrimonial constraints; low availability of adapted ground for boreholes; no groundwater or in water protection areas; too long distance to lake or river. In terms of retrofit, MFBs further face specific issues (technical, financial, organizational), namely lack of robust, standardized retrofit solutions, as well as landlord/tenant dilemma in relation to investment and repayment.

In existing MFBs, even without retrofit of the building envelope and when considering the hourly Swiss electricity mix (taking into account imports/exports), transition from fossil fuel boilers to HPs can in principle bring substantial CO_2 savings of 60 – 80% [6]. However, as highlighted in several recent P&D projects [7]–[9], high distribution temperatures penalize or impede proper operation of renewable heat production via HPs at building and DH level.

In this regard, building envelope retrofit, while primarily aiming at reducing the SH demand, can also contribute to lower SH distribution temperatures, by way of simple optimization measures on heating curves, flowrates, hydraulic circuit configuration [10]–[13], or possibly with selective replacement of heat emitters [14]. While the demand for DHW is independent of the building envelope and is subject to specific temperature regulation (in link with the legionella issue). Several temperature reduction techniques can in principle also be implemented [15], namely direct DHW production (without storage), or cascading of SH and DHW production to lower the return temperature to the heat production system.

At district level, lowering the DHN temperature has also been identified as a key measure for decarbonization of the heat supply [16] and reduce DHN operating costs [17], [18]. While lowering of DHN temperatures needs in principle to be implemented at the level of each building, in some cases optimization measures are limited, in particular in existing buildings. In this case local complementary high temperature heat production, namely with local booster HPs, could help for decarbonization at global scale [19]–[21].

1.2 Purpose of the project

In this context, combination of targeted envelope and system retrofit, along with optimization and/or replacement measures of SH/DHW distribution, appear as the most appropriate solution to lower the system temperatures and accelerate the integration of renewables. However, combinations of such measures have so far not been investigated in a systematic way, in particular in terms of lowering SH and DHW distribution/production temperatures, for more efficient integration of renewables and related decarbonization. Furthermore, the impact of combining optimization and targeted retrofitting measures at global district level and local building level needs to be assessed in more details.

T-DROP explores optimal combinations of targeted envelope retrofit and technical optimization of heat distribution systems in buildings, to lower heat distribution temperatures and decarbonize heat production with HPs and/or DHNs. Specific objectives are:

- For various building typologies, identify key technical measures for temperature reduction of heat distribution (SH and DHW), transition to renewable heat production, with or without targeted envelope renovation.
- Evaluate the impacts of such measures at building as well as at district level, in terms of energy mix, CO_2 reduction (direct and indirect) and cost, accounting for architectural and technical constraints.

1.3 Objectives

Based on the context and motivations presented above, this project aims to tackle the following research questions:

1. How to transition **from high to low temperature heat distribution** (SH and DHW) through the combination of **envelope retrofitting** measures and **heat distribution optimizations**, to facilitate renewable heat penetration?
2. What are the benefits of such measures, on **energy, environmental and economic KPIs**, at the level of buildings and districts?
3. In relation with these measures, **which heat production solution is the most appropriate**: centralized (DHN), decentralized (local HPs) or a combination of both?

The following specific objectives will be achieved within the project:

1. Quantification of the **temperature reduction potential for various typologies of MFBs** following optimization of heat distribution systems and different combinations of envelope retrofit measures.
2. Impact evaluation of **temperature reduction on heat production efficiency** for different heat production systems (in particular HP and DHN).
3. Quantification of **decarbonization potential for various typologies of building** following temperature reduction through a combination of targeted envelope retrofits, heat distribution systems optimization and fuel switch.
4. **DHN supply and return temperature reduction potential** following a combination of targeted envelope retrofits, heat distribution systems optimization and fuel switch on the most critical buildings.

2 Procedures and methodology

The project is divided into three main parts. The first part consists in defining and modeling building typologies of interest, and establishing a list of retrofitting scenarios. The second part consists in selecting and modeling optimization or replacement measures for the SH/DHW system. Finally, those numerical models of both building and SH/DHW system will be combined and tested on case studies to quantify the benefits on renewable heat integration and decarbonization of existing MFBs and neighborhoods.

Throughout the study, an extensive set of case studies from past and ongoing projects, with diverse and mixed building typologies, will be used to: i) characterize the building and system typologies; ii) test strategies for the reduction of SH and DHW production temperatures and integration of renewables.

2.1 Building typologies and envelope retrofitting measures

The first part of the study focuses on the building typologies and envelope retrofitting measures. There are two main objectives: i) to define and model building typologies of interest and their characteristics, including heat emitters, and ii) to establish a list of targeted building envelope renovation and improvement measures to reduce heat demand and SH temperature levels.

First, it will consist in selecting, defining and modelling the MFB typologies considered in this project. The selection process is based on the literature, such as architectural fact sheets developed in the eREN project [22], as well as follow-up projects carried out by the project partners (TypoRENO [23] and Historeno [24]). To limit the number of cases, the study focuses only on predominant MFB typologies representing the building stock in need of retrofitting measures.

Each considered typology will be defined and characterized by a set of parameters (envelope characteristics, SH and DHW demand …). These characteristics will be used to define the initial situation before envelope retrofitting measures and optimization or replacement of SH/DHW distribution are applied. Unlike previous work on this subject, focusing mainly on architectural aspects, the definition of the typologies will also include characteristics on the SH/DHW distribution system, as well as required temperature levels (supply/return). Each considered typology will then be modelled to produce hourly SH demand, combined with the required temperature levels (supply/return).

Finally, a list of targeted building envelope retrofit scenarios (window replacement, roof/façade insulation…) will be defined for each of the selected building typologies. The retrofit scenarios will then be implemented into the building models generated previously (initial situation), with the purpose of quantifying hourly SH demand and peak load reduction. Most importantly, the model will also consider the effect of oversized emitters on SH distribution temperatures.

2.2 Optimization and replacement of SH and DHW systems

The second part of the study focuses on the SH/DHW system. It has two objectives: i) to establish an inventory of replacement and optimization measures for SH/DHW distribution and production; ii) to develop the corresponding numerical models.

To this end, the first step will consist in listing retrofitting and optimization measures based on the literature, and categorize them according to the type of measure (regulation optimization, hydraulic modification, etc.). The feasibility and potential of the measures will be discussed with professionals (members of the advisory board) based on their experience and feedback from implementation projects. It will allow to identify the most promising measures in terms of energy demand and temperature levels reduction.

Finally, the last step consists in modelling the selected measures, either with a simple rule of thumb (if modelling is too complex or time consuming) or a more detailed energy model in TRNSYS. When possible, existing models from past projects (e.g. AirBiVal [25], PACs-CAD [26], Vergers [27], OPTIM-EASE [28], SolHOOD [29]…) will be used and adapted if necessary.

2.3 Decarbonization potential at building and district level

In the last part of the study, measures and strategies identified will be combined in various scenarios, representing different levels of system optimizations and retrofitting depth (partial to full). Using integrated simulation, the effects on energy, economic and environmental KPIs will be explored at two different levels:

- at building level, to identify the most cost-effective scenarios according to the building/heat distribution system typologies;
- at district level, for various configurations (new buildings, old buildings or a mix of both), to determine the benefits for the integration of local or remote renewables sources (with HPs and/or DHNs).

The studied buildings and districts will be based on case studies, as well as prospective districts. This will provide tangible results on a wide variety of situations, allowing the formulation of recommendations and guidelines for the related stakeholders throughout Switzerland. They will allow to orient and facilitate decision-making, and help focus on the most efficient measures facilitating the integration of renewable energies.

3 Analysis based on energy modeling

The beginning of the project consisted in conducting a literature review on existing MFB typologies (including heat emitters and SH distribution temperature levels), as well as possible measures for lowering temperature levels in MFBs. The aim is to define and characterize the initial situation, establish a list of targeted building envelope retrofitting measures and SH/DHW system optimization, as well as determine inputs and parameters for the energy modeling. This literature review will be consolidated throughout the project.

This section presents the outcomes of this literature review and discussions with project partners in terms of energy modeling (initial situation, parameters and inputs, as well as modeling strategy). As described in Figure 1, several categories of measures have been identified, based on the element of the system it is applied to: building envelope, heat emitters, distribution, heat transfer/storage and heat production.

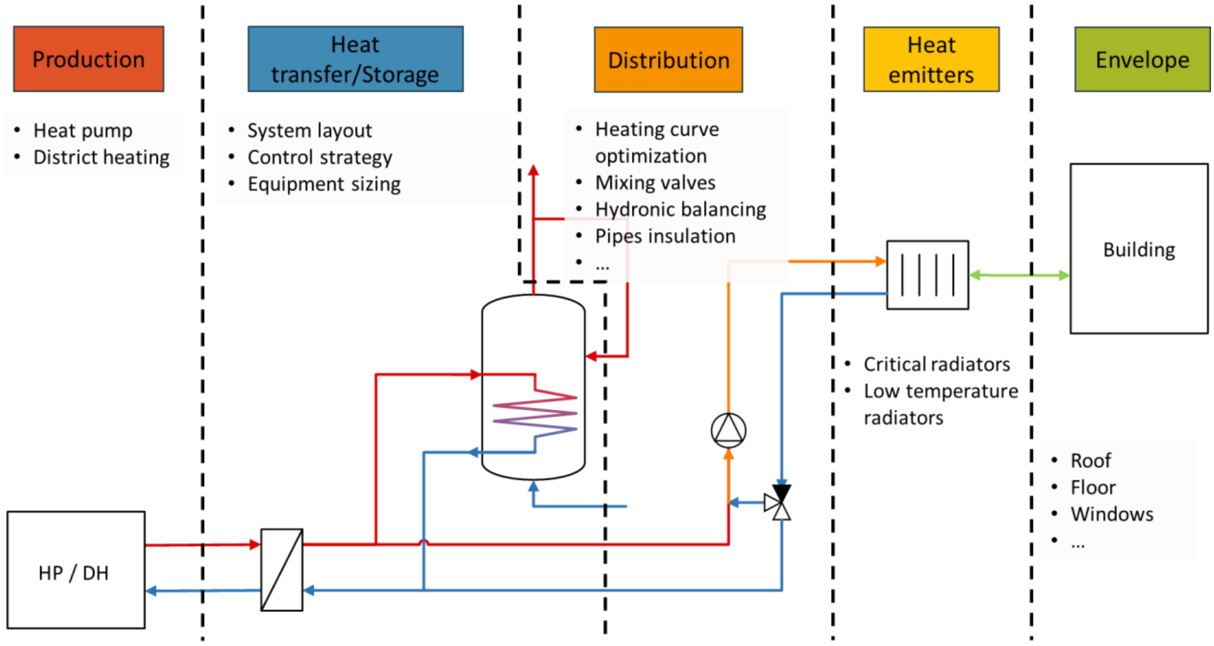

Figure 1: Overview of measures for lowering temperature levels per category

Building envelope

- Building typologies (initial situation) and corresponding envelope retrofitting measures will be based on factsheets from the eREN project [22] (developed for the French-speaking part of Switzerland) and the Solution Rénovation project [30] (developed for the Canton of Geneva).
- Predominant building typologies have been determined by analyzing Geneva's multifamily building stock. This analysis is based on the database provided by the Solution Rénovation project, in which the typology of most MFBs built before 1990 has been identified. Results show that, in Geneva, 4 typologies represent more than half the existing multifamily building stock built before 1990.
- The building will be modeled in TRNSYS using a single-zone RC model based on the ISO 13790 standard (TRNSYS Type5897) [31]. This model is a simplified single-zone building model, which includes heat losses (envelope, ventilation,…) and heat gains (solar, occupancy, equipment,…), and considers the building thermal capacity. It is a compromise between a detailed building model (e.g. produced using EnergyPlus), which allows for integrated simulation between the SH/DHW

system and the building model but requires significant time investment, and an hourly load curve which is faster to implement but prevents integrated simulation. Input parameters for the characterization of the selected building typologies and the retrofitting scenarios will be extracted from Lesosaï models generated in the eRen project.

Heat emitters

- Supply temperatures of existing SH distribution systems have been analyzed in Switzerland and in Sweden based on monitoring data [32], [33], and both analysis show similar results.
- An analysis of the CPEG's (Caisse de Prévoyance de l'Etat de Genève) multifamily building stock has confirmed that the vast majority of buildings built before 2000 have radiators as heat emitters. The study will therefore focus on radiators as heat emitters.
- Several recent studies have shown interest in thermostatic radiator valves to achieve energy savings [11], [34], [35]. However, the analysis of the CPEG's multifamily building stock confirmed that most buildings are already equipped with thermostatic radiator valves. This measure has therefore been eliminated from the list of relevant measures for the Swiss multifamily building stock.
- Several studies examine the benefits of replacing critical radiators to lower the supply/return temperature of the SH distribution system, rather than replacing all radiators [14], [36]. Furthermore, new technologies of radiators are now available, such as low temperature radiators with active ventilation [37].
- Heat emitters will be modeled using TRNSYS Type1231 from the TESS Component Libraries [38]. It calculates the heat transfer based on the temperature difference between the zone ambient air and the average fluid temperature in the heat emitter.

Distribution

- Several measures for lowering temperature levels have been identified from the literature and from discussions with project partners. These include the following:
    - Optimize the heating curve, to lower temperature levels and prevent apartments overheating.
    - Eliminate inappropriate mixing valves in the SH distribution [13]. Such valves were previously implemented for the operation with a fossil-fuel boiler, but are not suitable for systems with heat pumps or low temperature DH.
    - Hydraulic balancing of the SH distribution [39], [40].
    - Reduce DHW distribution losses, as it forces production at high temperature to maintain the whole distribution network around 55°C and prevent legionella proliferation.
- Several configurations of mixing valves can be modeled directly in TRNSYS using standard component libraries.
- Hydraulic balancing of the SH distribution will be modeled using heating curves and ΔT (or flowrate) measured in case studies for which detailed monitoring data are available

Heat transfer / storage

- There has been growing interest in small decentralized SST for instantaneous DHW preparation in each apartment [41]–[48]. Such systems are currently included in the catalogue of several companies in Switzerland. Compared to a conventional system with centralized DHW storage, a decentralized instantaneous DHW system offers the advantage of lower temperature levels (supply at 52°C instead of 55-60°C, according to SIA 385/1 standard [49]) due to the reduced risk of Legionella proliferation.

- Several studies have shown the importance of the control strategy for DHW preparation [50], [51]. In particular, staged control of DHW tank charging can improve stratification and lower return temperatures to the heat generator.
- Equipment sizing (tanks, HEX, etc.) can affect temperature levels due to low stratification of the DHW tank, undersized heat exchangers, etc.
- Several SST architectures will be analyzed to identify their pros and cons in terms of temperature levels, as well as evaluate the benefits of replacing an existing SST by another architecture. Selected SST architectures (Figure 2) are based on existing district heating networks located in Switzerland. Some of these networks are old DHN in need of lowering their temperature levels in the upcoming years/decades, and others are new low temperature DHN, namely:
    - Typical CAD-SIG SST [52]: one main heat exchanger, followed by another heat exchanger for DHW preparation and direct SH
    - "Les Vergers" SST [27]: two heat exchangers in parallel, one for SH and one for DHW preparation
    - "Le Marais-Rouge" SST [52]: cascaded DHW and SH heat exchangers
    - Primary side storage SST: two heat exchangers in parallel, one for SH and one for DHW preparation, with storage on the primary side for DHW preparation

  Case studies of two of these SST (CAD-SIG and "Le Marais-Rouge" SST) are described in section 4. It should be noted that such SST architectures can also represent different system layouts in case of decentralized heat production with a HP (without DH).

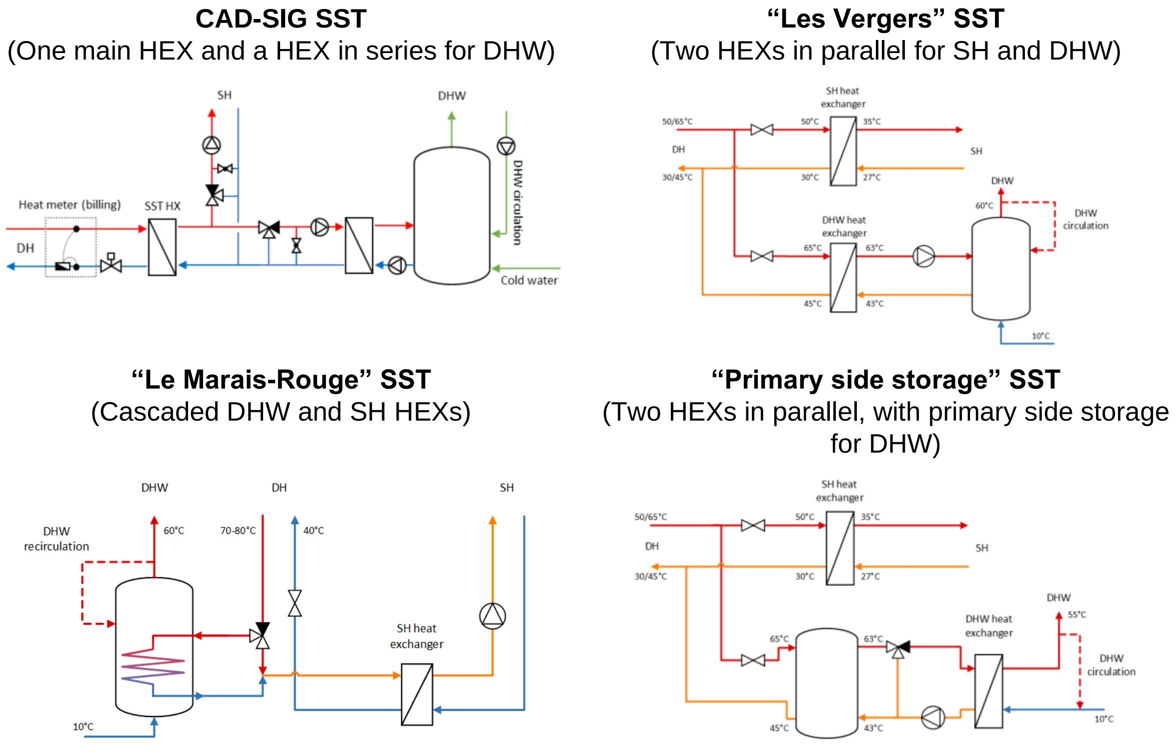

Figure 2: Description of selected SST architectures

Heat production

- At the building level, the study will focus on air-source HPs, with or without fossil fuel backup. Indeed, hybrid HP systems can reduce significantly CO_2 emissions of the heat production compared to existing systems [7], which for the most part rely entirely on fossil fuel boilers. Therefore, hybrid HP systems constitute an interesting solution as a temporary solution before building envelope retrofitting or when it is not possible to implement a monovalent system (noise emissions, structural constraints of the roof,…). It can also limit peak power usage in winter.
- At the district level, several DHN mix can be analyzed to evaluate the impact of lowering temperature levels on heat production efficiency and CO_2 emissions. For instance, the projected DH mix for Geneva's [52] and Lausanne's [53] DHN networks in 2035-2040 are very similar, namely: i) about 35% heat from HPs (geothermal, waste water treatment plant, lake), ii) 35- 45% waste heat recovery, and iii) 20-30% heat from wood or gas boilers.

Summary

Table 1 summarizes the measures currently selected per category, along with their corresponding modeling strategy and inputs/parameters. Several aspects will be refined in the upcoming months and tested on baseline simulations. This list of measures is expected to evolve over the course of the project, based on the literature review, preliminary results, discussions with project partners, and complexity of the modeling.

Energy modeling will mainly be conducted using the TRNSYS software [25], which allows to model both buildings and SH/DHW systems. Python is also used to generate all the building envelope retrofitting measures combination and simulate each combination in TRNSYS.

Table 1: Summary of measures for lowering temperature levels, as well as corresponding energy modeling strategy and inputs

	Measure	Data/Parameter/Input	Modeling strategy
Building envelope	Targeted retrofit	eREN and Solution Rénovation factsheets	RC model (Type5897)
	Full retrofit		RC model (Type5897)
Heat emitters	Replacement of critical radiators	Installed capacity?	Heat emitter model (Type1231)
	Replacement of existing radiators by new low temperature radiators	Manufacturer's data for low temperature radiators?	Optimized heating curve
Distribution	Elimination of inappropriate bypass and mixing valves	Predominant configurations according to Primas et al. (2014)	TRNSYS
	Hydraulic balancing	Case studies / literature?	Heating curve and flowrate (or ΔT)
Heat transfer/storage	System layout (or SST architecture in case of DH)	Existing case studies	TRNSYS
	Control strategy		
Production	Air-source heat pumps with/without fossil fuel backup	HP efficiency from case studies (e.g. AirBiVal project)	TRNSYS
	District heating	Existing case studies (DH mix, efficiency of heat generator, etc.)	

4 Case studies

Several case studies have been conducted in collaboration with other projects. All these case studies provide information regarding the challenges and benefits of lowering temperature levels in existing MFBs.

The first case study examines various scenarios for retrofitting the building envelope and integrating renewables in an existing MFB located in Lausanne. In particular, it includes an analysis of heat emitters sizing and potential optimization of the heating curve before and after retrofitting the building envelope.

Then, the second case study focuses on the issue of temperature reduction at substation/demand level in existing DH SSTs, based on monitoring of SSTs connected to Geneva's main DH (2nd generation DH). It allows to further tackle the issue of high DH return temperatures, and to identify if the problem lies on the secondary side (building and/or distribution system) or on the DH heat exchanger

Finally, the last case study examines innovative SSTs connected to a 4th generation DH located in Les Ponts-de-Martel. A specific monitoring campaign allows to characterize advantages of this SST architecture, which enables cascade preparation of DHW and SH. It is complemented by a numerical sensitivity analysis under diverse conditions of operation, in particular in terms of its potential for the Geneva context.

4.1 Renovation and integration of renewables for an existing multifamily building in Lausanne

A Bachelor's thesis was carried out at HEIG-VD on two multifamily buildings located in Lausanne, in collaboration with the Industrial Services of the city of Lausanne (SIL). The objective of this thesis was to study the impact of various optimization measures for heating distribution and envelope renovation on the performance of an air/water heat pump. This case study was conducted using tools regularly employed in engineering offices.

Selected buildings for this case study are two multifamily buildings constructed in 1963 (see Figure 3), with energy reference areas (ERA) of 1'630 m² and 1'407 m², comprising a total of 34 apartments. These two buildings have nearly identical characteristics, except for their slightly different lengths. The study was conducted simultaneously for both buildings since there is a single heat production system for both. These buildings underwent an initial renovation in 2000. Currently, heat production for space heating and domestic hot water is provided by a 200 kW gas boiler.

Figure 3: View of the multifamily buildings studied during the Bachelor project

The study of gas consumption allowed estimating the annual specific space heating requirements at 82 kWh/m²/yr. This value was compared to the space heating needs derived from the thermal balance performed on Lesosai: 77.4 kWh/m²/yr for building No. 10 and 83.9 kWh/m²/yr for building No. 12. The consumption of DHW amounts to 34 kWh/m²/yr.

The calorimetry revealed that the total thermal losses power for both buildings is 90 kW (for a reference outdoor temperature of -7°C). Furthermore, it allowed determining that some apartments, assessed under unfavorable conditions, do not have a real oversizing of terminal heat emitters, while others, deemed more favorable, were significantly oversized. This result confirms what is already reported in the literature [14]. Calorimetry also revealed that the current heating curve can be lowered due to the radiator oversizing. The optimized heating supply temperature regime is 56/46°C (instead of 60/40°C).

Various scenarios for building envelope retrofit and replacement of the heat producer were defined and evaluated for these buildings:

- **Scenario 1**: Integration of an air source heat pump (ASHP) operated in bivalent mode with the existing gas boiler (gas boiler + ASHP).
- **Scenario 2**: Roof and floor renovation + replacement of the gas boiler with an ASHP in bivalence with the existing gas boiler.
- **Scenario 3:** Roof and floor renovation + replacement of the gas boiler with an ASHP in bivalence with the existing gas boiler + installation of solar thermal collectors for DHW production.

For each scenario, the heating curve of the building was adjusted (Figure 4) by lowering the supply temperatures if the SH demand was lowered (oversized heat emitters). The performance of the heat production system was estimated using the Polysun software.

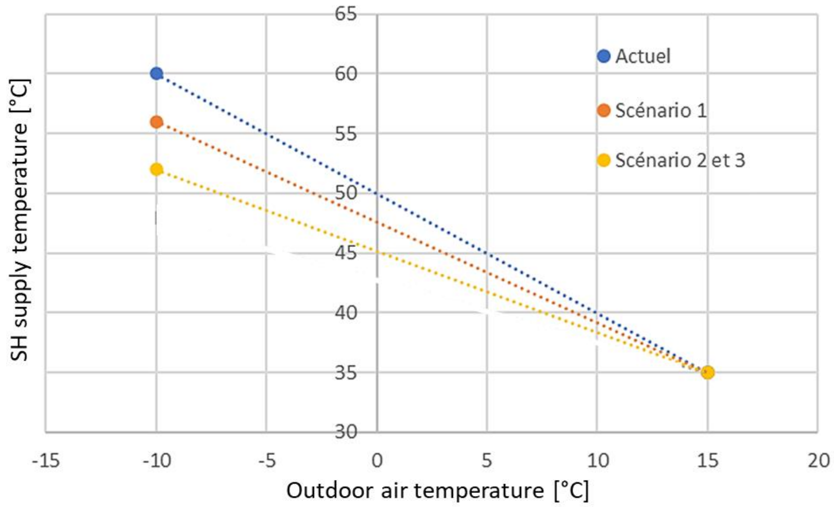

Figure 4: Heating curve for the SH supply temperature in each scenario

All scenarios result in a considerable reduction in the gas consumption of the buildings. The first scenario allows for an 83% reduction in gas consumption compared to the current consumption. By improving the roof and floor insulation, this reduction was even more significant, reaching 94%. The share of heat production covered by the ASHP for all the studied scenarios was higher than 80%. The ASHP Seasonal Performance Factor (SPF) was relatively constant between each scenario and corresponds to the value recommended by SFOE. Scenario 3 achieves the highest SPF, reaching 2.9, making it the most energy-efficient.

Furthermore, all the studied scenarios significantly reduce annual greenhouse gas (GHG) emissions generated by heat production:

- **Scenario 1:** -60% GHG emissions
- **Scenario 2:** -73% GHG emissions
- **Scenario 3:** -78% GHG emissions (thanks to the integration of solar thermal collectors)

The emissions per unit Energy Reference Area (ERA) in Scenario 2 and those in Scenario 3 approach the indicative values presented in the SIA 2040 technical document (goals of the Society for a 2000 Watts future).

A financial analysis of the different scenarios was conducted over 20 years with a discount rate of 3% and an annual energy cost escalation rate of 6%. Costs were assessed for each renovation measure, taking into account available subsidies in the canton of Vaud. The Levelized Cost of Heat (LCOH) including envelope retrofitting cost was calculated for all three scenarios (see Table 2). The results indicate that it is possible to reduce heat production costs by integrating an ASHP in bivalence with the current gas boiler and without envelope renovation. Scenario 3 also presents a more favorable LCOH than the current cost. This is partly due to substantial subsidies received for the solar thermal installation. Scenario 2 shows that renovation measures slightly increase the discounted cost of heat compared to the current situation.

Table 2: Levelized Cost of Heat (LCOH) including the cost of the envelope retrofitting for the current situation and the for three scenarios defined above

Scenario	**LCOH [ct/kWh]**
Current situation	18.0
Scenario 1	15.2
Scenario 2	19.2
Scenario 3	17.5

This case study should be extended with a new scenario in order to investigate the impact of replacing critical radiators in some apartments. The oversizing of the heat emitters allowed to reduce the supply temperature of the SH distribution system, and it could be even further reduced if critical radiators were replaced. This temperature reduction should allow reducing the gas consumption and increasing the ASHP SPF. Resulting LCOH and GHG emissions should in principle be reduced compare to Scenario 1.

4.2 Monitoring of temperature levels in existing substations of a 2nd generation DH network (CAD-SIG DH in Geneva)

This study was carried out in collaboration with the SWEET DeCarbCH project (in particular WP7.1 [52]). The aim is to tackle the issue of analysis and temperature reduction techniques at substation/demand level in existing DH SSTs, using the case study of Geneva's main DH (CAD-SIG). Typical SST architecture in this DH (Figure 5) is also representative of other old DHs in Switzerland, such as Lausanne's main DH.

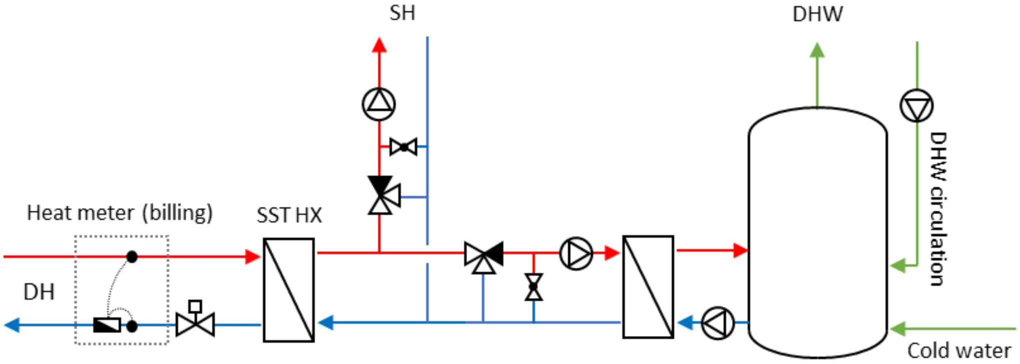

Figure 5: Most common architecture for substations connected to CAD-SIG DH (Geneva's main DH)

Massive integration of renewable heat in district heating (DH) networks is conditioned by reduction of its operative temperatures, which in turn depends on the temperature level of the individual substations (SSTs), on the secondary side of the heat exchanger (distribution/demand). The 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 particularly complex (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 depends to a large extent on pre-existing conditions.

CAD-SIG DH (located in Geneva) is a 2nd generation urban DH network from the 1960's, delivering 359 GWh of heat to 214 substations, with supply/return temperatures around 110°C/70°C. It relies on a mix of 71% natural gas and 29% renewables and waste heat.

A ranking of the SSTs connected to this network (using the excess flow method) has shown that a considerable number of SSTs have primary temperature differences below their respective targets, indicating potential problems in their operation.

Specific temperature measurement campaigns are carried out on the primary and secondary sides of the main heat exchangers of a selection of CAD-SIG SSTs, characterized by excess flow. In case of high DH return temperatures, this analysis allows to identify if the problem lies on the secondary side (building and/or distribution system) or on the primary side (heat exchanger size, regulation, etc.).

A specific monitoring campaign (Figure 6), involving the installation of temperature sensors on a total of thirteen counterflow HEXs in the Avanchets district, shows that the return temperatures on the primary side are high, despite relatively low return temperatures on the secondary side. This inconsistency leads to the identification of problematic heat exchangers within certain SSTs, with low NTU.

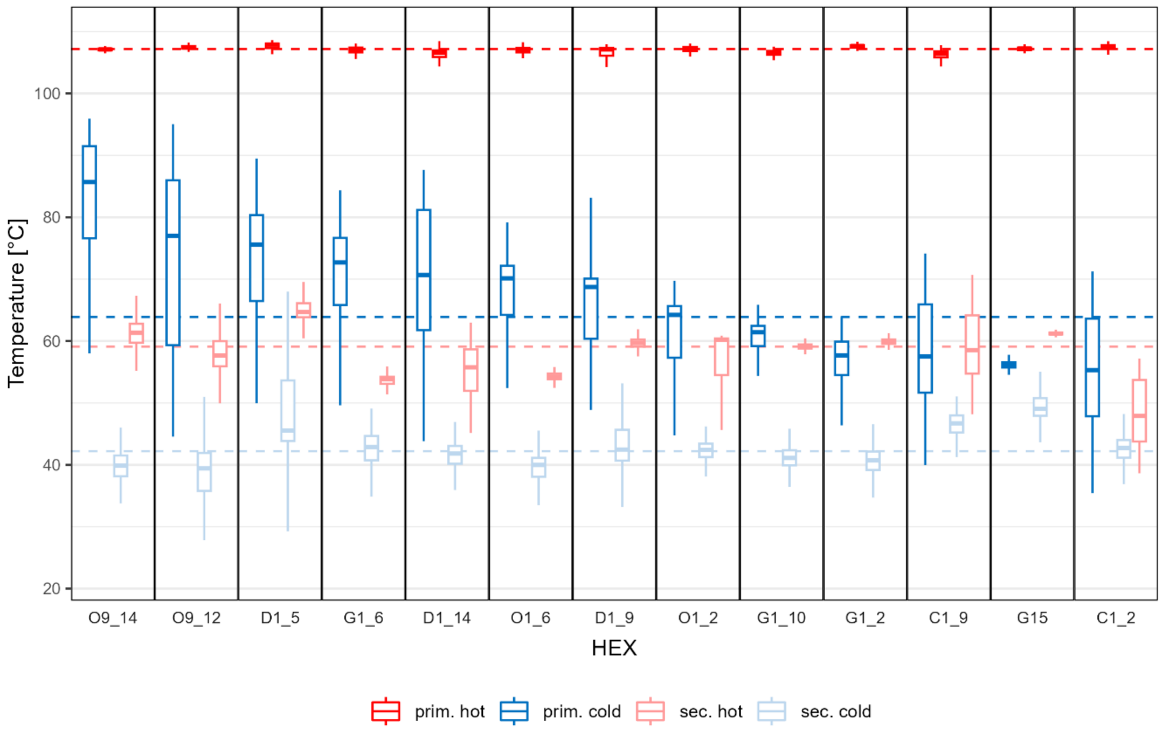

Figure 6: Temperatures measured during the 2 coldest weeks of the first campaign at "Les Avanchets" (03.12.2022 to 17.12.2022). The horizontal dashed lines represent the medians of all 13 monitored counterflow HEX. 10-minute data.

Additional measurement campaigns in other districts and SSTs reveal further heterogeneity in temperatures and behaviors. Comparison between well-performing heat exchangers and those with malfunctions or poor control, emphasize the importance of monitoring combined with regulation optimization, for more efficient operation of the heat exchanger.

Overall, this analysis provides a better understanding of the behavior of selected SSTs and highlights the importance of factors such as setpoint temperatures, control and heat exchanger design. As a main result, we observe that in most cases the secondary side is not responsible for the high return temperatures on the primary side. Although surprising, such is undoubtedly an easier situation for the DH operator, since the HEXs are under its own responsibility and management. Complementary optimizations on the secondary side, under responsibility of the building owners, should of course also be carried out if necessary.

4.3 Monitoring and simulation of an innovative substation with cascade preparation of DHW and space heating ("Le Marais-Rouge" DH in Les Ponts-de-Martel)

This study was carried out in collaboration with the SWEET DeCarbCH project (in particular WP7.1 [52]). It consists in analyzing temperature levels of innovative SSTs from "Le Marais-Rouge" DH, in particular their primary return temperature. SSTs connected to this DH have an innovative cascade architecture (Figure 7) which allows second-stage cooling: hot water from the DH first passes through the internal DHW tank heat exchanger, and then through the SH plate heat exchanger.

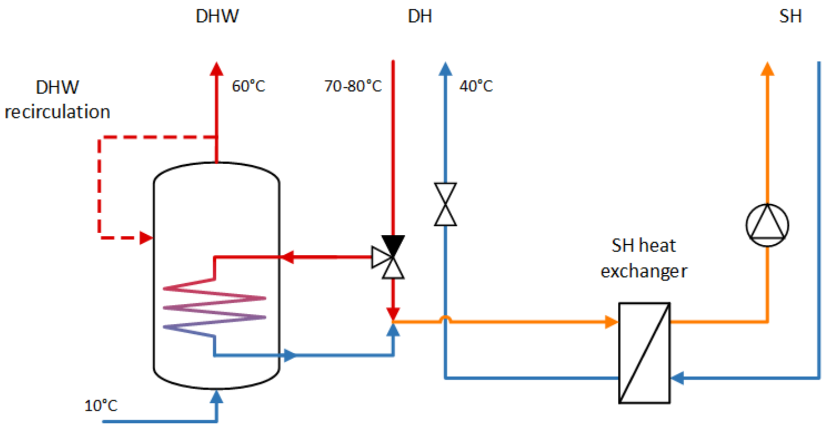

Figure 7: Substation architecture used in "Le Marais-Rouge" DH, with two-stage cascade

"Le Marais-Rouge" DH (located in Les Ponts-de-Martel) is a 4th generation rural DH network from 2007, delivering 5.8 GWh to 88 substations, with supply/return temperatures of 80°C/40°C. It is predominantly powered by 99% wood and 1% heating oil, resulting in significantly lower carbon emissions than CAD-SIG.

This DH is an example of a new generation of DH. Its innovative substation architecture enables cascade production of DHW and SH, with optimized temperature control and a focus on energy efficiency. This architecture is particularly well-suited to the context of Les Ponts-de-Martel, where weather conditions generate a higher share of space heating, especially during the mid-season. Furthermore, the substation integration with a cooperative model, involving consumers, facilitates access to secondary heat distribution systems, promoting overall efficiency and consumer engagement.

The study focuses on two SSTs of "Le Marais-Rouge" DH, for which a detailed monitoring campaign allows to characterize the temperature regimes with cascade preparation of DHW and SH. It is complemented by numerical simulation, which allows to assess the resulting temperature levels on DH for this substation architecture under other operating conditions, particularly in terms of its potential for the Geneva context.

Detailed measurements on two SSTs, carried out between February and May, show that their cascade architecture yields low return temperatures (ranging between 40 and 50°C). During the measurements, the cold side pinch on the SH heat exchanger doesn't exceed 3°C and the efficiency is close to 90%.

In summer (July and August), second stage cooling is not possible (no SH load). To achieve lower return temperatures in summer, special attention should hence be paid to control logic, DHW tank stratification and sizing of the internal heat exchanger.

To determine if such SST architecture could lead to low return temperatures on DH networks in Geneva, the "Le Marais-Rouge" DH SST was modeled, calibrated and simulated for different conditions of operation. Analyzed cases included different climates (Geneva and La Chaux-de-Fonds), DHW heat exchanger surface area (2 m^2 and 4 m^2), as well as different DH supply temperatures (65°C, 83-70°C and 90°C). Calibration results show that the simulated SST adequately reproduces the behavior of the actual SST in terms of energy balance and return temperatures.

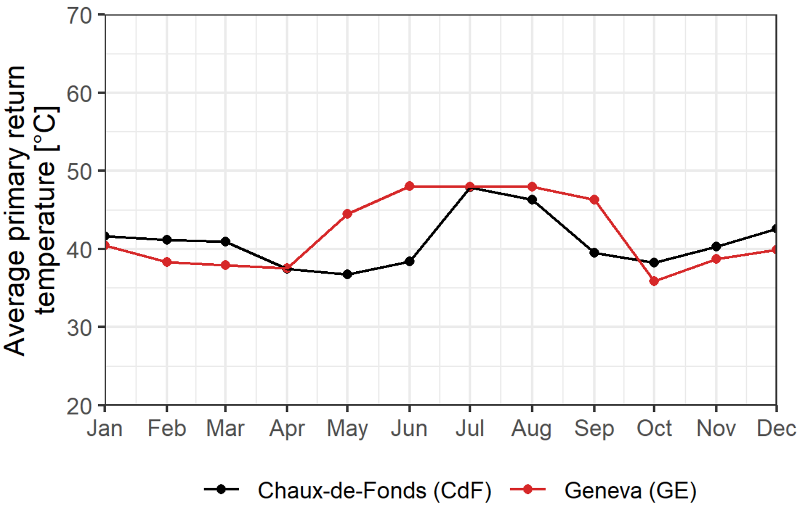

Figure 8: Monthly return temperature of the SST for two different climates

Main results of the sensitivity analysis are as follows:

- Climate does not have a significant impact on the annual heat weighted return temperature of the SST. However, due to the shorter heating season in Geneva, the SST experiences higher return temperatures for a prolonged period (Figure 8).
- Installing a DHW heat exchanger with a large surface area allows to increase the ΔT during periods with no SH demand, which occur throughout summer but also more sporadically during mid-season. However, during the heating season, the DH return temperature highly depends on the return temperature from the building SH loop, as well as the efficiency of the SH heat exchanger. In such SST architecture, it is hence particularly important to optimize the SH loop, for achieving the lowest possible DH return temperature.
- During the heating season, the DH supply temperature mainly influences the operation of the DHW system, but not of the DH return temperature. However, during the summer, special attention should be paid to the DH supply temperature, as well as DHW heat exchanger area and setpoint, which play a major role in the DH return temperature.

It is important to note that this study was carried out on non-retrofitted buildings, i.e. with a high share of space heating demand. Results might be different for new buildings, with a heat demand dominated by domestic hot water.

Additional simulations would be interesting to evaluate the benefits of replacing a typical CAD-SIG SST architecture by a cascaded SST architecture such as “Le Marais-Rouge” SSTs. In particular, it would consist in developing a calibrated model of a CAD-SIG SST, and then compare it with the cascaded SST for the same conditions of operation (SH and DHW load, temperature levels of the distribution,…).

5 Next steps

The next steps of the study will be as follow:

- **Select the most promising actions for lowering temperature levels** based on their implementation cost, expected result on the temperature levels, ease of implementation and replication potential. In particular, this will consist in consolidating the literature review carried out to date, as well as engaging discussions with project partners who are active in the field.
- **Combine the building model with the SH/DHW system model into a reference case** to serve as basis for the elaboration of relevant scenarios. The aim is to obtain preliminary results, validate the proposed modeling strategy and identify potential modeling limitations.
- **Establish the list of building envelope retrofitting scenarios** for the selected building typologies, with corresponding input parameters for the energy model.
- **Develop models of the selected SST / building heating system architectures.** This will allow to compare results in terms temperature levels from/to the heat generator for a reference case, as well as identify the most promising actions based on the strengths and weaknesses of each system architecture.

6 National and international cooperation

The T-DROP project bears a strong link with current nation-wide projects in which both UNIGE and HEIG-VD are actively participating, namely:

- Renowave (Innosuisse Flagship project), in particular SP2.1 (FlexiRenove), which focuses on design and technical improvement of fuel-switch, i.e. from fossil to renewable energy via individual heat pumps in existing multifamily buildings.
- DeCarbCH (SFOE SWEET project), in particular WP7.1, which focuses on strategies and potentials of temperature reduction on existing district heating networks.

The T-DROP project results will directly contribute to the objectives of both projects.

In addition, HEIG-VD is also involved in the TypoRENO project [23], which aims at developing roadmaps for energy renovation of buildings with a patrimonial value. It is limited to the Canton of Vaud's building stock but encompasses a diverse range of multifamily typologies. The outputs of this project will be used in T-DROP to establish building typologies and define realistic envelope retrofitting measures. Furthermore, results from T-DROP will be complementary to this project as it will combine targeted envelope retrofitting measures to SH/DHW system retrofit, optimization and/or replacement measures.

Furthermore, the advisory board of the T-DROP project includes stakeholders active in the field, with diverse areas of expertise. It will ensure the proposed measures are in line with actual challenges and compatible with technical, financial, and legal constraints. It is composed by the following partners:

- Loïc Quiquerez, Carolina Fraga, Hermine Wöhri (SIG)
- Cédric Blondel (SIL)
- Jean-François Mino (MBG)
- François Baud (François Baud & Thomas Früh Atelier d'architecture SA)
- Anne-Valérie Narath (DGE-DIREN)
- Fabien Poumadère (Service des énergies de la ville d'Yverdon-les-Bains)
- Nadège Vetterli (SFOE)

All these partners are actively involved in the energy transition, namely with the DHN deployment and optimization for valorization of centralized renewable energy sources, setting up of fuel-switch program (from fossil fuel boilers to HPs) as well as building retrofit, in particular for multifamily buildings (MFBs).

7 Communication

NA

8 Publications

NA

9 References

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