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**Interim report from 13 December 2024**

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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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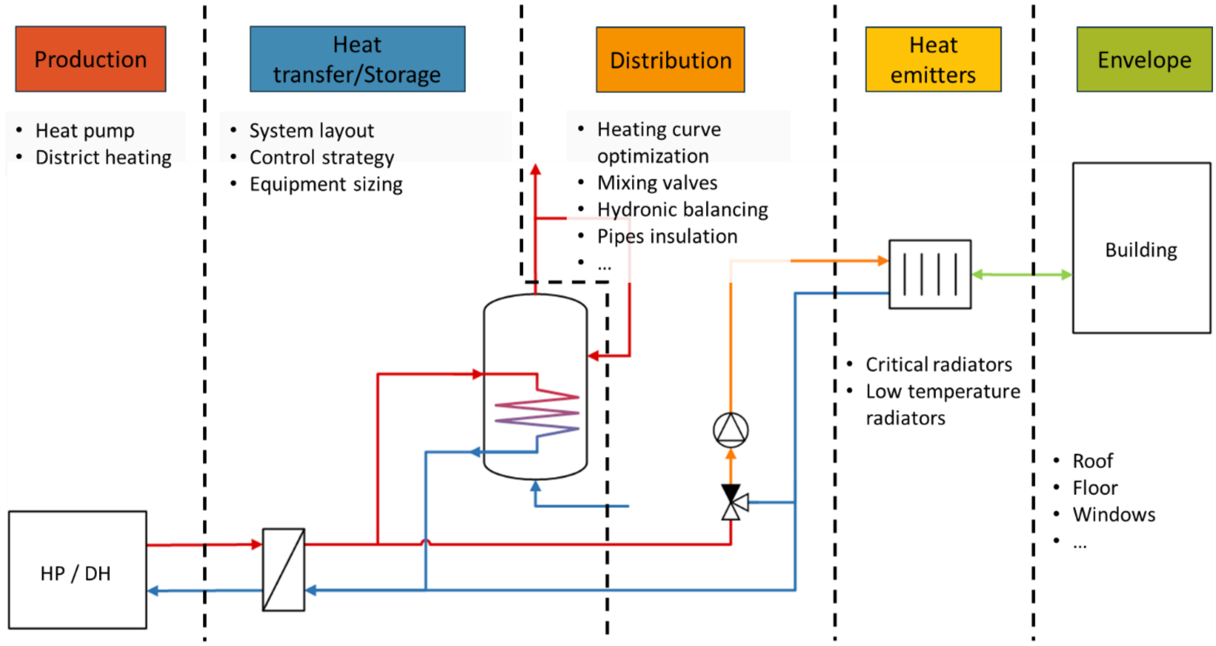

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# Summary

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. The focus is set on multifamily buildings in dense districts.

Work completed to date includes: i) defining and modeling building typologies of interest, and establishing a list of retrofitting scenarios, ii) selecting and modeling the most relevant space heating/domestic hot water (SH/DHW) system typologies, iii) defining energy, economic and environmental performance indicators to assess the impact of retrofitting and optimization measures on the system, and iv) developing an integrated building and system model, and calculating the performance indicators for a baseline scenario.

The next phase of the project will first consist in selecting and modeling the most promising optimization measures for each SH/DHW system typology. A sensitivity analysis will then combine these measures with targeted envelope retrofitting measures to evaluate their impact on temperature levels and performance indicators. This will allow to identify the most cost-effective scenarios according to the building and SH/DHW system typologies.



# Zusammenfassung

Als Voraussetzung für die massive Integration erneuerbarer Energien und die Dekarbonisierung mithilfe von Wärmepumpen oder Fernwärme untersucht das Projekt T-DROP optimale Kombinationen von gezielter Renovierung der Gebäudehülle und technischer Optimierung der Wärmeverteilungssystemen, um die Verteilungstemperaturen zu senken. Der Schwerpunkt bezieht sich auf Mehrfamilienhäusern in dicht bebauten Stadtvierteln.

Die bisher durchgeführten Arbeiten umfassen: i) die Definition und Modellierung relevanter Gebäudetypologien sowie die Erstellung einer Liste von Sanierungsszenarien, ii) die Auswahl und Modellierung der relevantesten Typologien für Heizungs- und Warmwassersysteme (SH/DHW), iii) die Definition von Energie-, Wirtschafts- und Umweltindikatoren zur Bewertung der Auswirkungen von Sanierungs- und Optimierungsmaßnahmen auf das System schliesslich iv) die Entwicklung eines integrierten Modells für Gebäude und Systeme sowie die Berechnung der Leistungsindikatoren für ein Basisszenario.

In der nächsten Projektphase werden zunächst die vielversprechendsten Optimierungsmaßnahmen für jede Typologie von SH/DHW-Systemen ausgewählt und modelliert. Anschließend wird eine Sensitivitätsanalyse durchgeführt, bei der diese Maßnahmen mit gezielten Sanierungsmaßnahmen an der Gebäudehülle kombiniert werden, um deren Auswirkungen auf die Temperatur- und Leistungsindikatoren zu bewerten. Dies sollte es ermöglichen, die kosteneffizientesten Szenarien je nach Gebäudetypologie und SH/DHW-System zu identifizieren.



# 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.

Les travaux réalisés à ce jour incluent : i) la définition et la modélisation des typologies de bâtiments, ainsi que d’une liste de scénarios de rénovation, ii) la sélection et la modélisation des typologies de

systèmes de chauffage et d’eau chaude sanitaire (ECS) les plus pertinents, iii) la définition d’indicateurs de performance énergétique, économique et environnementale pour évaluer l’impact des mesures de rénovation et d’optimisation, et iv) le développement d’un modèle intégré de bâtiment et système de chauffage/ECS, et le calcul des indicateurs de performance pour un scénario de référence.

La prochaine phase du projet consistera d’abord à sélectionner et modéliser les mesures d’optimisation les plus prometteuses pour chaque typologie de système de chauffage/ECS. Une analyse de sensibilité combinera ensuite ces mesures avec des mesures ciblées de rénovation de l’enveloppe afin d’évaluer leur impact sur les niveaux de température et les indicateurs de performance. Cela permettra d’identifier les scénarios les plus rentables en fonction des typologies de bâtiments et de systèmes de chauffage/ECS.

# Contents

# List of abbreviations

| | |
|---|---|
| ASHP | Air-source heat pump |
| DHN | District heating network |
| DHW | Domestic hot water |
| ERA | Energy reference area |
| HEX | Heat exchanger |
| HP | Heat pump |
| MFB | Multifamily building |
| P&D | Pilot and demonstration |
| SH | Space heating |
| SFOE | Swiss Federal Office of Energy |
| SST | Substation |

# 1 Introduction

## 1.1 Context and motivation

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 (related to 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].

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 and related decarbonization. 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.

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 in terms of energy mix, $CO_2$ reduction (direct and indirect) and cost, accounting for architectural and technical constraints.

## 1.2 Project 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 performance indicators?

The following specific objectives will be achieved within the project:

1) Quantify the temperature reduction potential for various typologies of MFBs following optimization of heat distribution systems and different combinations of envelope retrofit measures.
2) Evaluate the impact of temperature reduction on heat production efficiency for different heat production systems (in particular HP and DHN).
3) Quantify the decarbonization potential for various typologies of building following temperature reduction through a combination of targeted envelope retrofits, heat distribution systems optimization and fuel switch.

# 2 Approach and method

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

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

For practical reasons, the modeling tasks for both the building and SH/DHW system is carried out in parallel, as described in Figure 1. These models are later on combined into an integrated building and SH/DHW system model to be able to accurately evaluate the temperature levels. Finally, a sensitivity analysis is conducted for different retrofit and optimization scenarios to quantify the impact of the implemented measures on renewable heat integration and building decarbonization.

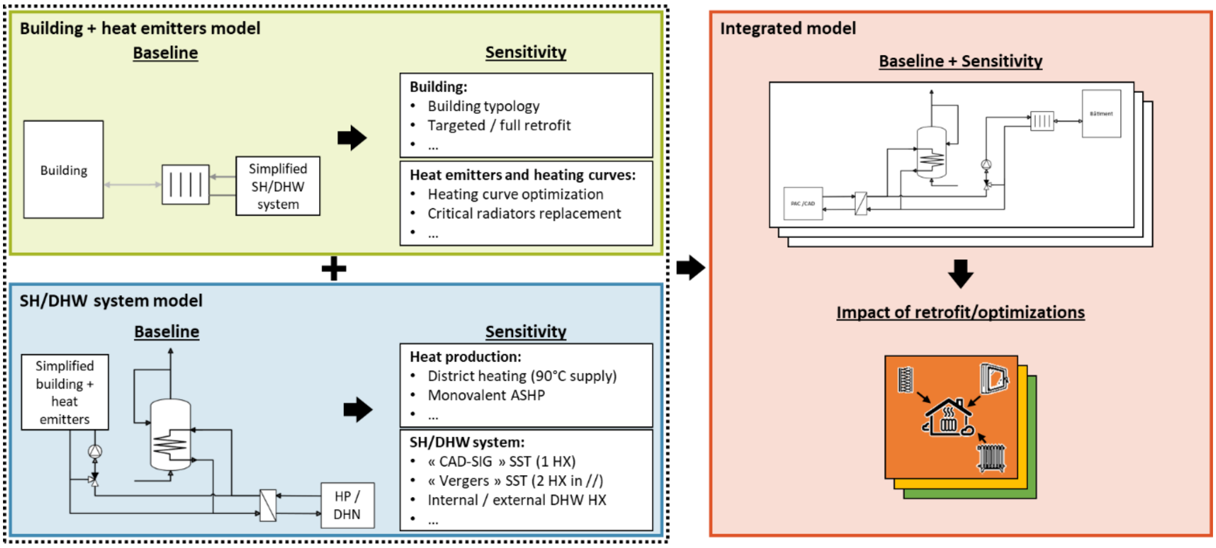



Figure 1: Global modeling workflow of the project

## 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 three main objectives: i) to define building typologies of interest and their characteristics, ii) to establish a list of targeted building envelope retrofit to reduce SH demand and temperature levels, and iii) to model the building typologies of interest and targeted retrofitting measures.

The MFB typologies considered in this project are selected based on the literature, in particular on architectural fact sheets developed in the eREN project [19], as well as follow-up projects (TypoRENO [20] and Solution Rénovation [21]). To limit the number of cases, the study focuses only on predominant MFB typologies representing the building stock in need of retrofitting measures.

Predominant typologies are identified based on discussions with architects from the Renowave project [22], as well as the Solution Rénovation project database [23], which assigns a building typology to a significant portion of Geneva's MFB stock.

Each considered typology is defined and characterized by a set of parameters (envelope characteristics, SH demand …). These characteristics are used to define the initial situation before envelope retrofitting measures are applied. Unlike previous work on this subject, focusing mainly on architectural aspects, the definition of the typologies also includes characteristics on the heat emitters, as well as required temperature levels (supply/return). Each considered typology is then 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…) is defined for each of the selected building typologies. The retrofit scenarios are then 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 also considers the effect of oversized emitters on SH distribution temperatures.

For more detailed information, see Chapters 3 and 4.

## 2.2 Optimization and replacement of SH and DHW systems

The second part of the study focuses on the SH/DHW system. It has three objectives: i) to select and model SH/DHW system typologies of interest, ii) to establish an inventory of the most-promising replacement and optimization measures for SH/DHW distribution and production for each type of SH/DHW system; iii) to develop the corresponding numerical models.

The first step consists in modelling the most common SH/DHW systems, such as air-source heat pump (ASHP) systems and DHN substations, to determine the strengths and weaknesses of these systems in terms of temperature levels. The aim is to identify the most promising retrofitting and optimization measures for each type of system in terms of energy demand and temperature levels reduction.

Then, the next step consists 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.

Finally, the last step consists in modelling the selected replacement and optimization measures, either with a simple rule of thumb (if modelling is too complex or time consuming) or a more detailed energy model in TRNSYS [24].

For more detailed information, see Chapter 4.

## 2.3 Decarbonization potential

In the last part of the study, measures and strategies identified are 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 performance indicators are explored to identify the most cost-effective scenarios according to the building and SH/DHW system typologies. The results will allow to orient and facilitate decision-making, and help focus on the most efficient measures enabling the integration of renewable energies.

For more detailed information, see Chapter 5.

# 3 Buildings typologies and envelope retrofitting measures

The first part of the study focuses on the definition of building typologies and envelope retrofitting measures. There are three main objectives: i) to define building typologies of interest and their characteristics, ii) to establish a list of targeted building envelope retrofit to reduce SH demand and temperature levels, and iii) to model the building typologies of interest and targeted retrofitting measures.

## 3.1 Selected buildings typologies

The selection process is based on the literature, particularly on architectural fact sheets developed in the eREN project [19], as well as its follow-up projects, TypoReno [20] and Solution Rénovation [21]. All three projects aimed to identify building typologies within the Swiss multifamily building stock in need of retrofitting, and to define detailed envelope retrofitting scenarios (partial and full) taking into account technical constraints. These scenarios include estimated SH demand before and after retrofitting, as well as investment costs. Such building typology sheets are used, among other things, to facilitate and accelerate the renovation process for building owners.

To limit the number of cases, the study focuses only on predominant MFB typologies representing the Swiss building stock in need of retrofitting. Predominant typologies are identified based on discussions with architects from the Renowave project [22], as well as the Solution Rénovation project database [23]. The latter assigns a building typology to a significant portion of Geneva's MFB stock built after 1945. With a statistical analysis, it is then possible to determine the predominant building typologies in terms of number of buildings, energy reference area (ERA) and heat demand (see Figure 2 and Table 1). It should be noted that this analysis was carried out on the portion of the multifamily building stock in Geneva that has both an assigned typology and available heat demand data. It is also limited to MFB built between 1945 and 1990 (about 53% of the MFB ERA in GE), because the Solution Rénovation project focused only on that construction period. Ultimately, this subset represents approximately 40% of Geneva's total MFB stock ERA.

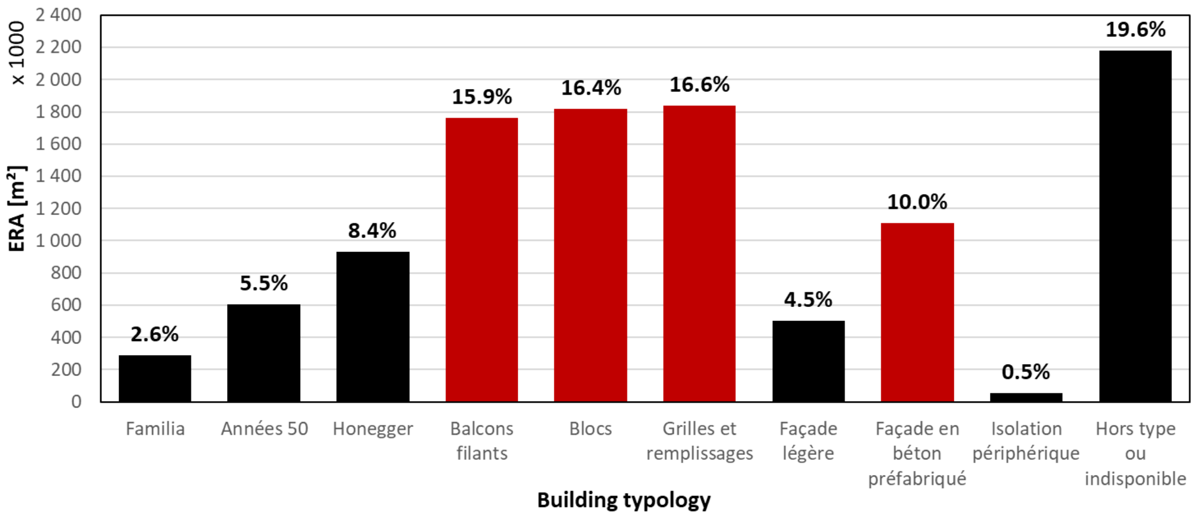



Figure 2: Distribution of the ERA of MFB in Geneva by building typology according to the "Solution Rénovation" project (MFB buildings built between 1945 and 1990, with an ERA > 500 m²)

Table 1: Predominant building typologies in Geneva's multifamily building stock [25]

| Typology name | eREN sheet No. | % ERA in GE MFB stock | % buildings in GE MFB stock | % heat demand in GE MFB stock |
|---|---|---|---|---|
| **Balcons filants** | 5 | 15.9% | 13.9% | 16.1% |
| **Blocs** | 7 | 16.4% | 15.9% | 15.9% |
| **Grilles et remplissage** | 8 | 16.6% | 14.7% | 17.3% |
| **Préfabriqué** | 10 | 10.0% | 9.0% | 9.4% |

This analysis was complemented by discussions with architects, which led to the addition of eREN typology No4, common in the German-speaking part of Switzerland, but not predominant in the canton of Geneva. The resulting predominant typologies are illustrated in Figure 3. They correspond to the construction period 1950-1990.

| eREN No4 | eREN No5 | eREN No7 | eREN No8 | eREN No10 |
|---|---|---|---|---|
| | "Balcons filants" | "Blocs" | "Grilles et remplissage" | "Préfabriqué" |
| 1950-1970 | 1960-1975 | 1960-1975 | 1960-1975 | 1975-1990 |

Figure 3: Selected predominant multifamily building typologies (pictures from eREN project sheets [19] and typology names from Solution Rénovation project [21])

## 3.2 Envelope retrofitting scenarios

The eREN project ("Approche globale pour l'enveloppe du bâtiment - Rénovation énergétique", 2012-2015) [19] was funded by the HES-SO. This project aimed at evaluating and comparing different renovation scenarios for various existing multifamily building typologies. At the beginning of the project, the post 1945 building stock has been decomposed in 15 building typologies. The ultimate objective was to define the minimum renovation scenario for each building typology allowing to reduce the specific SH needs below the limit defined by the Swiss standards for building retrofitting. This project represents a solid base for the retrofitting of post 1945 buildings. For each building typology, different retrofitting scenario were generated. Each scenario was then evaluated in terms of SH reduction and cost.

The T-DROP project adopted the eREN building typologies as its initial reference point. As previously discussed, the eREN project offers a valuable foundation by categorizing buildings into specific typologies, identifying suitable retrofitting measures for each type, and quantifying the corresponding costs and reductions in SH demand.

It should be noted that additional MFB typology sheets are available from the TypoReno project [20]. They provide a step-by-step renovation scenario for each typology, along with associated investment costs and GHG emissions. Unlike eREN typology sheets, produced in 2012-2015, investment costs correspond to current construction costs, and the TypoReno sheets offer step-by-step renovation scenarios rather than full retrofitting scenarios. This approach aligns more closely with the T-DROP project, which explores both targeted and full retrofitting scenarios. However, the TypoReno project primarily focuses on historical buildings with patrimonial value, mainly built before 1945. As a result, predominant MFB typologies identified in section 3.1 are not represented.

Nevertheless, additional building typology sheets are currently under developed within the TypoReno project and will be examined in the next phase of the T-DROP project to identify potentially relevant MFB typologies for this study.

In the meantime, the T-DROP project will focus on the eREN typology sheets for the selected predominant typologies. In order to use them in this project, several adaptations and modifications have been made in order to correct several errors in the building model available, to adapt the reference weather station and to update the retrofitting cost. This section details the approach and the adaptations made to the selected building typologies from the eREN project.

### Method for adapting retrofitting scenarios

The eREN project demonstrated that a global approach to energy renovation, involving a complete overhaul of the thermal envelope to comply with the SH demand limit (Qh,li) from the SIA 380/1:2009 standard [26], is economically difficult to promote compared to the potential energy savings. The approach developed in the T-DROP project is to decompose the retrofitting process in several steps (as done in the TypoReno sheets), i.e. to apply each measure one after the other and to assess the influence on SH demand (Qh) and retrofitting investment costs. Using the typologies from the eREN project means reworking the basic building thermal model for each building, as well as extracting and adapting the investment costs between the year of publication of the eREN project and the current T-DROP study.

In the eREN project, the normalized SH demand for each building typology were calculated using LESOSAI software, in accordance with the SIA 380/1:2009 calculation method. As the building typologies were based on case studies of existing MFB located in the cantons of Vaud, Fribourg and Geneva, the reference weather stations for each of these cantons were used to calculate the SH requirements according to each building location.

Table 2 gives a comparison between both projects.

Table 2: Comparison between the eREN project and the T-DROP project

| Adaptations | eREN project | T-DROP project |
|---|---|---|
| SIA standard for calculation of SH demand (Qh) | SIA 380/1:2009 | SIA 380/1:2016 |
| Reference weather station | Depends on the actual building location (VD, GE or FR) | Geneva (GE) |
| Year of completion | 2012-2015 | 2023-2025 |
| Building reference state | According to the state observed during the visits (including past retrofitting actions) | Building with its initial characteristics |

The LESOSAI files produced for the eREN project were retrieved by the T-DROP project team. These were modified/adapted in order to be able to apply the phased approach to renovation measures. The modifications described below were made to the LESOSAI files:

1) **Adaptation of the calculation method:** Geneva's energy legislation requires the application of the SIA 380/1 standard, 2016 edition. The canton of Vaud is also planning to apply this standard as part of its energy law update. It was decided to apply this calculation method instead of the one used in the eREN project (SIA 380/1:2009 standard). The SIA standard update impacts only slightly the building SH needs.

2) **Modification of the reference weather station:** As the eREN case studies are divided between the cantons of Vaud, Fribourg and Geneva, the reference weather stations for each of these cantons were used to calculate SH requirements. This study of the influence of a step-by-step approach on representative typologies of the Geneva building stock involves adapting the weather station and choosing the reference station for the canton of Geneva, i.e. the Geneva-Cointrin weather station.

3) **Updating of renovation investment costs:** The eREN project was published in 2015. The investment costs have been updated by applying the Swiss construction price index for renovation/conversion in the Lake Geneva region, using October 2015 as the base value and April 2024 as the correction value [27] (the latest index published at the time of this work). The index used is 110.3 (base 100 October 2015). Building renovation costs in the Lake Geneva region therefore increased by an average of 10% between October 2015 and April 2024.
   A step-by-step approach requires a long-term vision of the work to be carried out and thus a renovation that can be described as comprehensive. In this context, the overhead costs defined in the eREN project have been allocated pro rata to each renovation measure.
   The investment cost per renovation measure is expressed per square meter of ERA. In the next phase of the project, the resulting investment costs will be submitted to architects for validation.

4) **Existing condition without taking into account renovations carried out between the year of construction and the present:** Some of the buildings analyzed in the eREN project had already undergone renovations (e.g., window replacement, roof renovation, attic insulation) at the time of the assessment. For the T-DROP project, it was decided not to take these renovations into account and to return the existing condition analyzed in eREN to the initial condition of the building (building envelope). This adaptation of the building thermal balance, in terms of heat loss coefficients, is based on values taken from the literature [28]. The adaptation of the calculation method and the modification of the weather station for the five buildings may lead to different results for the SH demand (Qh) than those obtained in the eREN project.

#### Application of the methodology to eREN No5 building typology

The procedure described above have been applied to the selected building typologies for the T-DROP project (see description in section 3.1). In this section, the methodology described above is applied to the eREN No5 building typology.

This building typology corresponds to adjoining multifamily building built in 1960-1975. This building typology has 6-storey or more, and is located in peri urban zone. Its architecture is characterized by in-situ concrete facade, flat roof and sloping balconies and concrete floor with continuous slab. The case study selected to represent this typology is shown in Figure 4.


Figure 4: Picture of the building representing eREN No5 building typology. This building is located in Onex (GE).

For this building typology, the following retrofitting measures (as defined in the eREN project) were selected in order to reduce the SH needs below the specific SH needs limit defined by the SIA 380/1:2009 standard:

- Façade external insulation including thermal bridge insulation: U-value is reduced from 1.53 to 0.17 W/m².K after insulation
- Basement slab insulation: insulation with 10 cm mineral wool (U-value from 2.14 to 0.18 W/m².K after insulation)
- Replacement of double-glazed windows with triple-glazed windows with the following characteristics: Ug ~ 0.4 W/m².K, Uf ~ 1.2 W/m².K and g-value ~ 0.37

In the eREN project, those retrofitting measures were cumulated in order to reduce the building SH needs below the specific SH needs limit as defined by SIA 380/1:2009 standard. In the T-DROP project, the normalized thermal balance of the building according to SIA380/1:2016 standard was determined for the possible combination of these retrofitting measures. For each retrofitting scenario, the specific SH demand and the specific thermal power were defined using the LESOSAI software. The retrofitting costs were also evaluated using the methodology described above. The CECB building thermal efficiency class was also determined for all scenarios. Table 3 shows the results for each retrofitting scenario.

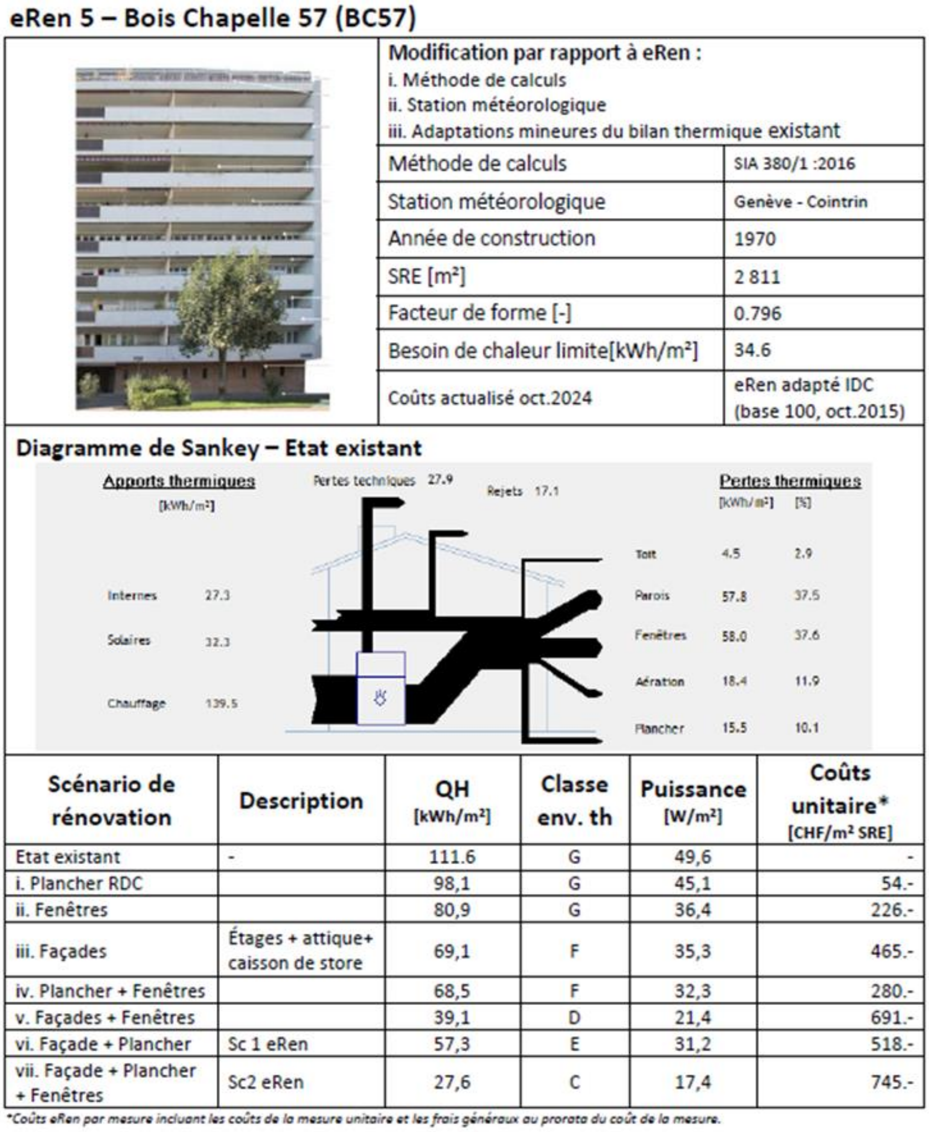
Table 3: Characteristics of each retrofitting scenario defined for the eREN No5 building typology

| No | Retrofitting scenario | SH demand (Qh) [kWh/m²$_{ERA}$] | CECB energy class | Specific power [W/m² $_{ERA}$] | Total retrofit cost [CHF] | Specific cost [CHF/m²$_{ERA}$] |
|---|---|---|---|---|---|---|
| **0** | Initial condition | 111.6 | G | 49.6 | | |
| **0'** | Current condition (roof renovated according to case study building) | 110.5 | G | 49.3 | | |
| **1** | Slab (ground floor) | 98.1 | G | 45.1 | 151 794 | 54 |
| **2** | Windows | 80.9 | G | 36.4 | 635 286 | 226 |
| **3** | Façade | 69.1 | F | 35.3 | 1 307 115 | 465 |
| **4** | Slab + Windows | 68.5 | F | 32.3 | 787 080 | 280 |
| **5** | Façade + Windows | 39.1 | D | 21.4 | 1 942 401 | 691 |
| **6** | Façade + Slab | 57.3 | E | 31.2 | 1 456 09 | 518 |
| **7** | Façade + Slab + Windows | 27.6 | C | 17.4 | 2 094 195 | 745 |

For each building typology selected for the T-DROP project, a sheet was compiled with the following information:

- Short description of the building typology
- Definition of retrofitting scenarios combining one or more retrofitting measures
- Characteristics and specific costs for each retrofitting scenario
- Specific SH demand, energy class and specific power for SH for each scenario

Figure 5 shows the "T-DROP" sheet for eREN No5 building typology.



**eRen 5 – Bois Chapelle 57 (BC57)**

**Modification par rapport à eRen :**
i. Méthode de calculs
ii. Station météorologique
iii. Adaptations mineures du bilan thermique existant

| | |
|---|---|
| Méthode de calculs | SIA 380/1 :2016 |
| Station météorologique | Genève - Cointrin |
| Année de construction | 1970 |
| SRE [m²] | 2 811 |
| Facteur de forme [-] | 0.796 |
| Besoin de chaleur limite[kWh/m²] | 34.6 |
| Coûts actualisé oct.2024 | eRen adapté IDC (base 100, oct.2015) |

**Diagramme de Sankey – Etat existant**



| Scénario de rénovation | Description | QH [kWh/m²] | Classe env. th | Puissance [W/m²] | Coûts unitaire* [CHF/m² SRE] |
|---|---|---|---|---|---|
| Etat existant | - | 111.6 | G | 49,6 | - |
| i. Plancher RDC | | 98,1 | G | 45,1 | 54.- |
| ii. Fenêtres | | 80,9 | G | 36,4 | 226.- |
| iii. Façades | Étages + attique+ caisson de store | 69,1 | F | 35,3 | 465.- |
| iv. Plancher + Fenêtres | | 68,5 | F | 32,3 | 280.- |
| v. Façades + Fenêtres | | 39,1 | D | 21,4 | 691.- |
| vi. Façade + Plancher | Sc 1 eRen | 57,3 | E | 31,2 | 518.- |
| vii. Façade + Plancher + Fenêtres | Sc2 eRen | 27,6 | C | 17,4 | 745.- |

**Coûts eRen par mesure incluant les coûts de la mesure unitaire et les frais généraux au prorata du coût de la mesure.*

Figure 5: T-DROP sheet for eREN No5 building typology showing the building typology characteristics and summarizing the different retrofitting scenarios considered

## 3.3 Building modeling

To evaluate renovation scenarios and link the building's SH system to them, we opted for a simplified numerical building model, Type 5897, developed for TRNSYS in [29] and based on the ISO13790:2008 standard (hourly method) [30]. This model offers several advantages, including a relatively small number of parameters and inputs, as well as a very short computation time. In contrast to detailed multizone models such as EnergyPlus, IDA-ICE, TRNSYS Type 56 and Pléiade-Comfie, Type 5897 is easy to parameterize, enabling efficient analysis of a large number of scenarios at an hourly time step.

**Description of Type 5897 from ISO13790:2008**

The ISO13790:2008 standard uses the electrical-thermal analogy to model heat flows in a building. Thermal resistances and capacities, as well as heat loads, are modelled using an analogous electrical circuit consisting of 5 resistors, 1 capacitor and 4 generators (see Figure 6). These models are commonly referred to as the 'RC model' (R: resistance, C: capacitance) and are more precisely identified by the number of each element, in this case 'R5C1'. The resolution at hourly (and sub-hourly) time steps is performed with the TRNSYS software in Type 5987 using the method described in Annex C of the ISO13790 standard.

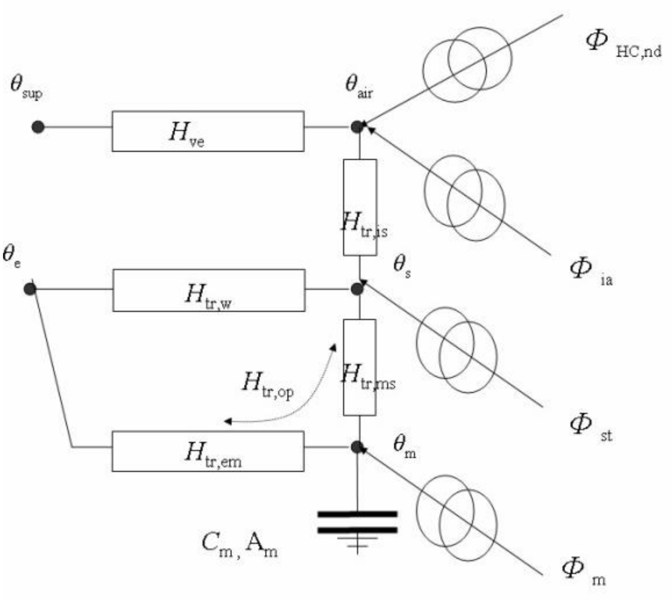



Figure 6: R5C1 thermal model diagram [30]

The R5C1 model takes into account heat loss due to ventilation ($H_{ve}$) and transmission through opaque ($H_{tr,op}$) and glazed ($H_{tr,w}$) walls. The ventilation heat transfer coefficient $H_{ve}$ is directly related to the temperature of the indoor air $\theta_{air}$ and the temperature of the air supplied by the ventilation $\theta_{sup}$ ($\theta_{sup} = \theta_e$ is used for the calculations). The heat transfer coefficients through the glazed walls $H_{tr,w}$ and through the opaque walls $H_{tr,op}$ are defined between the external temperature $\theta_e$ and that of the central node (on the inside of the wall) $\theta_s$, which represents the temperature of the internal surfaces of the building. This node is then coupled to the air node of the building by the coupling heat transfer coefficient $H_{tr,is}$, which characterises the convective heat transfers between the walls and the air. In this model, the opaque walls have an effective thermal mass that allows them to store part of the heat. This phenomenon is modelled as an electrical capacitor and is characterised by $C_m$ (thermal capacity of the building), $A_m$ (surface area of the effective thermal mass) and $\theta_m$ (internal temperature of the walls). In the case of glazed windows, their thermal capacity is neglected, i.e. they do not store heat and the heat transfer coefficient is not coupled to the thermal mass of the building.

The model considers four energy inputs, represented by generators:

- $\Phi_{HC,nd}$: heat flow produced by the space heating or air conditioning system,
- $\Phi_{ia}$, $\Phi_{st}$ and $\Phi_m$ are calculated to correctly distribute the internal $\Phi_{int}$ and solar gains $\Phi_{sol}$ to the different nodes according to the ISO13790 standard.

Table 4 and

Table 5 show the parameters and the inputs for Type 5897. Inputs differ from parameters as they can be changed at every type step of the simulation.

Table 4: Type 5897 parameters

| Parameter | Description | Unit |
|---|---|---|
| Cm | Internal heat capacity of the building or building zone | J/K |
| Am | Effective mass area | m² |
| Af | Conditioned floor area of Energy Reference Area (ERA) | m² |
| Htr_w | Thermal transmission coefficients of glazed walls and windows | W/K |
| his | Thermal transmission coefficient between internal air and the wall surface (by default: 3.45) | W/(m².K) |
| hms | Heat transfer coefficient between nodes m and s (by default : 9.1) | W/(m².K) |
| xat | Ratio between the internal surfaces area and the floor area (by default : 4.5) | - |
| Nsurf | Number of surfaces to deal with for passive solar gains | - |
| Tair_set_H | Set point temperature for heating the building | °C |
| Tair_set_C | Set point temperature for cooling the building | °C |

Table 5: Type 5897 inputs

| Inputs | Description | Unit |
|---|---|---|
| Text | Ambient temperature | C |
| Tsup | Temperature of the air supplied in the ventilation system | C |
| Pint | Internal passive gains | kJ/h |
| Hve | Thermal transmission coefficient due to ventilation | W/K |
| Htr_op | Thermal transmission coefficient of opaque (inertial) building elements | W/K |
| Isol,i | Solar irradiation on surface i | kJ/(h.m²) |
| Fshob,i | Shading reduction factor from external obstacles for the solar effective collecting area of surface i | - |
| Asol,i | Effective solar collecting area of surface i | m² |
| Ploss_GLO,i | Heat flow due to thermal radiation to the sky from building element i | kJ/h |

### Procedure for model parametrization and inputs definition in T-DROP

As described in the previous sections, buildings studied in the T-DROP project are based on building typologies and renovation scenarios defined and analyzed in related projects (eREN, TypoRenoVD) using the LESOSAI software. In the T-DROP project, several procedures for the parameterization of Type 5897 have been developed to allow a more or less automated transfer of data from LESOSAI building model to the TRNSYS model presented above (Type 5897).

Figure 7 illustrates the methodology for parameterizing the TRNSYS model and the results it generates. First, the characteristics and properties of the building envelope are automatically extracted from the LESOSAI building model. Next, the parameters and inputs required for the TRNSYS model are calculated. Using these inputs, the TRNSYS model simulates the building's thermal losses and gains.

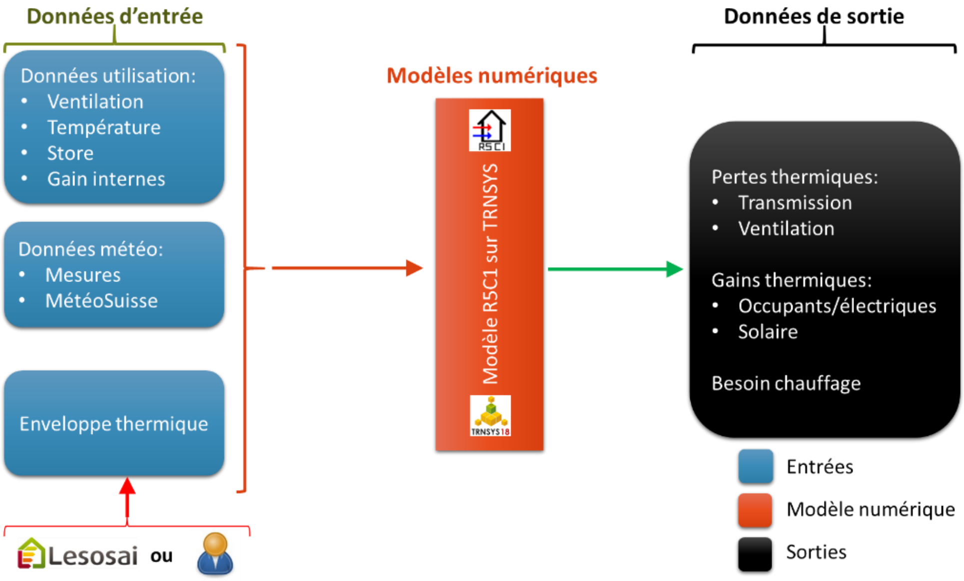



Figure 7: Procedure to define TRNSYS Type 5897 model inputs and parameters and to compute the building space heating and cooling needs

### TRNSYS building model validation

In order to validate the TRNSYS building model presented above based on Type 5897, measured SH needs collected from an existing non-renovated multifamily building have been used. This building is located in the heart of the Cité Nouvelle d'Onex, overlooking the Avenue du Gros-Chêne (see Figure 8). It is part of an apartment block, built in the early 1960s (1963). This rental complex consists of two blocks of semi-detached buildings, 36-38 and 40-42, facing south-west and north-east. This building has 8 stories and an energy reference area of 5'357 m² for each block. The building typology corresponds to eREN No5 typology ("Balcons filants") (see section 3.1). In 2008, the 40-42 block has been retrofitted to the Minergie standard. The other block (36-38) has not been retrofitted. In order to quantify the real SH needs reduction following the retrofitting, the thermal energy needs of both blocks have been monitored in 2008-2010. A complete description of the building, the retrofitting project and an analysis of the thermal energy needs is available in a scientific report published by the University of Geneva [31]. The model validation is based on the SH needs of the non-retrofitted block.

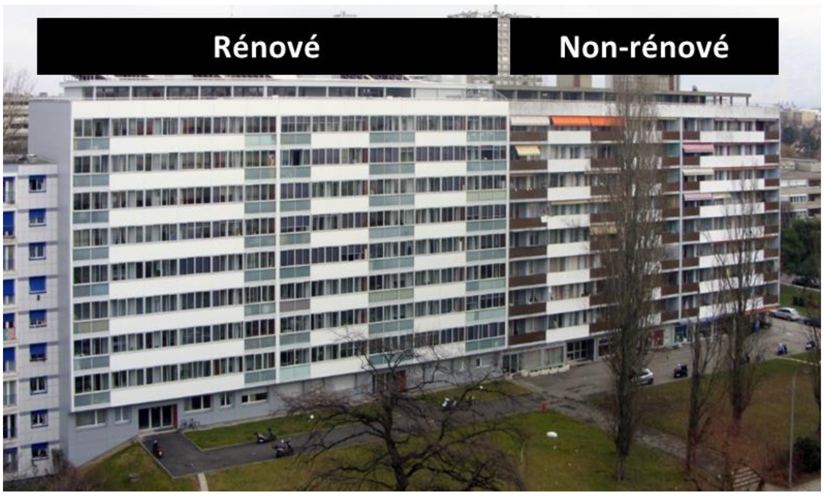



Figure 8: Picture of the "Gros-Chêne" building with the retrofitted block (left) and non-retrofitted block (right) [31]

The TRNSYS outputs of the Gros-Chêne building model were validated using two approaches:

1) A comparison with the daily and monthly monitored space heating demands
2) A comparison with the monthly outputs from the LESOSAI model of the Gros-Chêne building

The results of these comparisons are detailed in this section.

The monitoring data are first compared to the results of the TRNSYS building model on a monthly and daily basis. To compare the TRNSYS model with the monitoring data, the following assumptions are made:

- Indoor temperature setpoint = 22.5 °C (as per monitored indoor air temperature)
- Average internal heat gains = 16.58 kW (or 59'685 kJ/h and annual heat gain = 27.1 kWh/m²), calculated based on standard SIA values
- Weather: on-site measurements (outdoor temperature, horizontal solar radiation)
- Constant shading of glazed surfaces (taken from the LESOSAI model of the building)

Figure 9 shows the monthly SH consumption (in MJ/m²) for two sets of data: data from consumption measurements (monitoring) and a simulation carried out with TRNSYS18. The hatched bars represent the monitoring data, while the dotted bars represent the simulation results. The differences between the measurements and the simulation are quite small (< 5%) in winter, when SH consumption is highest, and increase in the low season (spring and autumn) as SH demand decreases. The errors cancel each other out on an annual basis, resulting in a relative deviation of only 0.2% for the annual SH needs. Table 6 shows the relative monthly and annual differences.

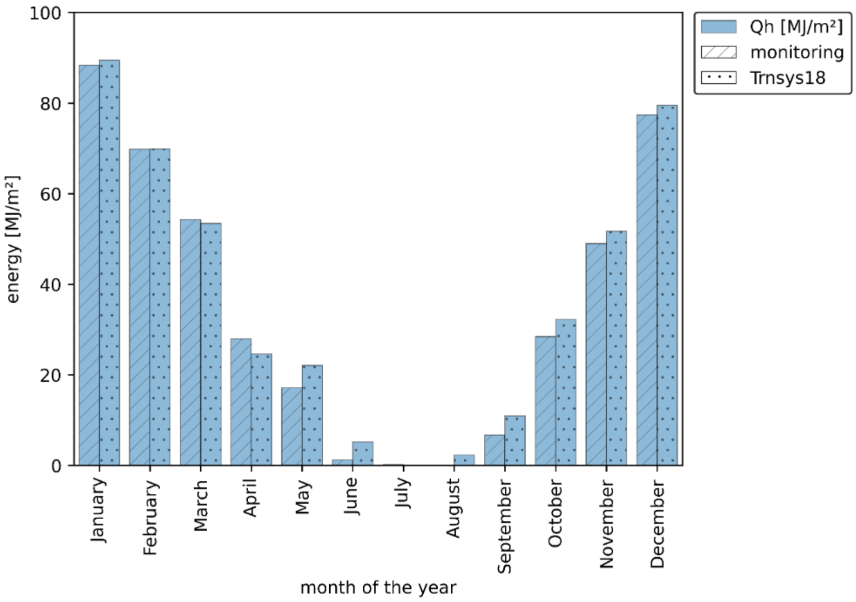



Figure 9: Monthly comparison of SH needs (Qh) in MJ/m² between monitored data for the Gros-Chêne building and TRNSYS18 simulation results for a whole year. The hatched bars represent measured values, while the dotted bars represent simulated values.

Table 6: Relative differences between SH needs monitored and simulated in TRNSYS. Relative differences are not taken into account for the summer months (June, July, August), but are included in the annual total SH needs.

| Month | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $\delta Qh$ [%] | -1.2 | -2.8 | -5.7 | -18.4 | 17.4 | - | - | - | 37.2 | 5.9 | 1.3 | -0.2 | **0.2** |

At the daily level, Figure 10 (top) shows the comparison of the daily SH consumption profile of the building between the monitoring (in blue) and the TRNSYS simulation (in orange), and at the bottom a comparison of the same data in a scatter plot.

The temperature setpoint of 22.5°C results in high SH consumption in summer. Defining a heating period would eliminate this phenomenon. The cvRMSE is acceptable (12.6%) for this granularity and the level of detail of the input data (in particular given the constant internal gain and constant shading).

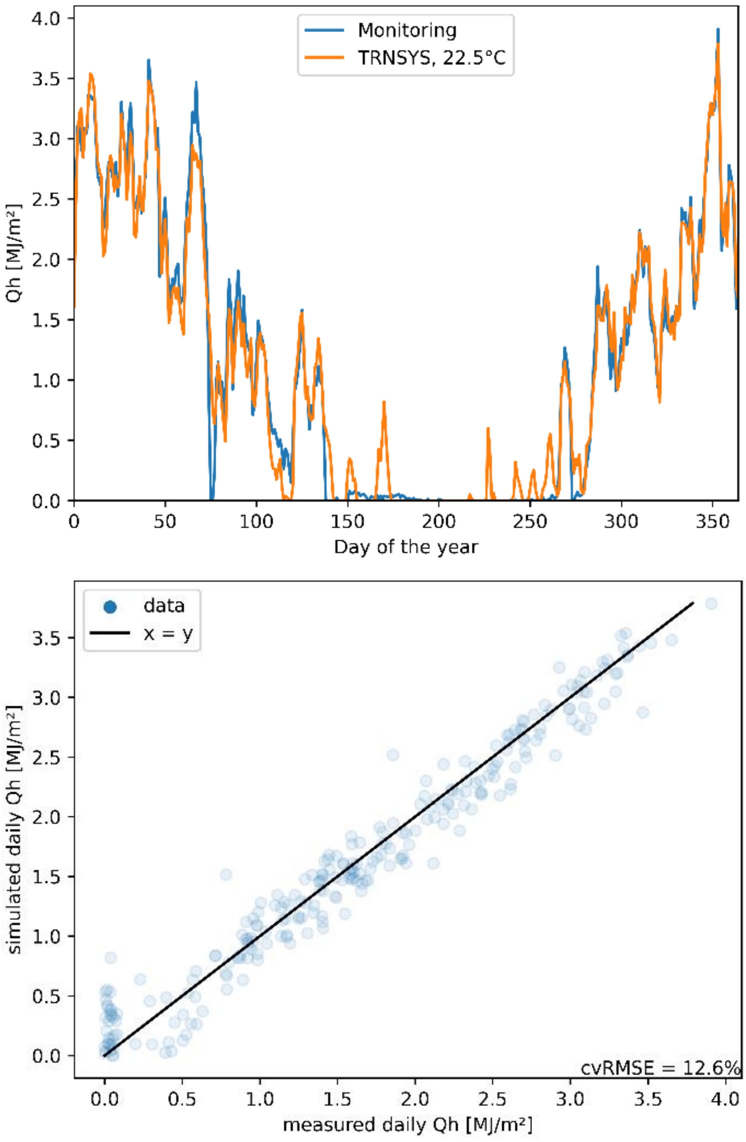



Figure 10: Comparison of the daily SH consumption (Qh) in MJ/m² from the monitoring data and the TRNSYS simulation with an indoor temperature setpoint of 22.5°C. Top: time profile over a whole year; bottom: scatter plot around the bisector.

In order to complete the validation of the TRNSYS model, and in particular to ensure that the various heat losses and gains are correctly accounted for and distributed, a comparison was made between the TRNSYS model and the SIA 380/1 thermal balance produced by the LESOSAI software. The following assumptions were made for this study:

- Temperature setpoint = 20 °C
- Average internal heat gain = 16.58 kW (59'685 kJ/h and annual heat gain = 27.1 kWh/m²)
- Weather: on-site measurements (outdoor temperature, horizontal solar radiation)

Note that the weather used in the LESOSAI model was adapted to the monitored weather. The irradiation on the south, east, north and west orientations used in LESOSAI were calculated from the monitored global horizontal irradiation using the TRNSYS Type 16 model.

Figure 11 shows the monthly transmission losses (QT) and infiltration losses (QV) as well as the solar (Qs), internal (Qi) and space heating (Qh) gains for the LESOSAI simulation (hatched bar) and TRNSYS 18 (dotted bar). The relative differences between these models are shown in Table 7. Since the input data were identical in both cases, there were no significant errors in the internal contributions (only rounding errors). On the other hand, there are more or less significant differences for the other components of the heat balance. The largest relative difference is for air exchange losses (QV) with -12% per year. On the other hand, losses and gains during the main winter months are sufficiently well modelled. The errors for SH consumption are less than 10% from October to March and -1.5% annually.

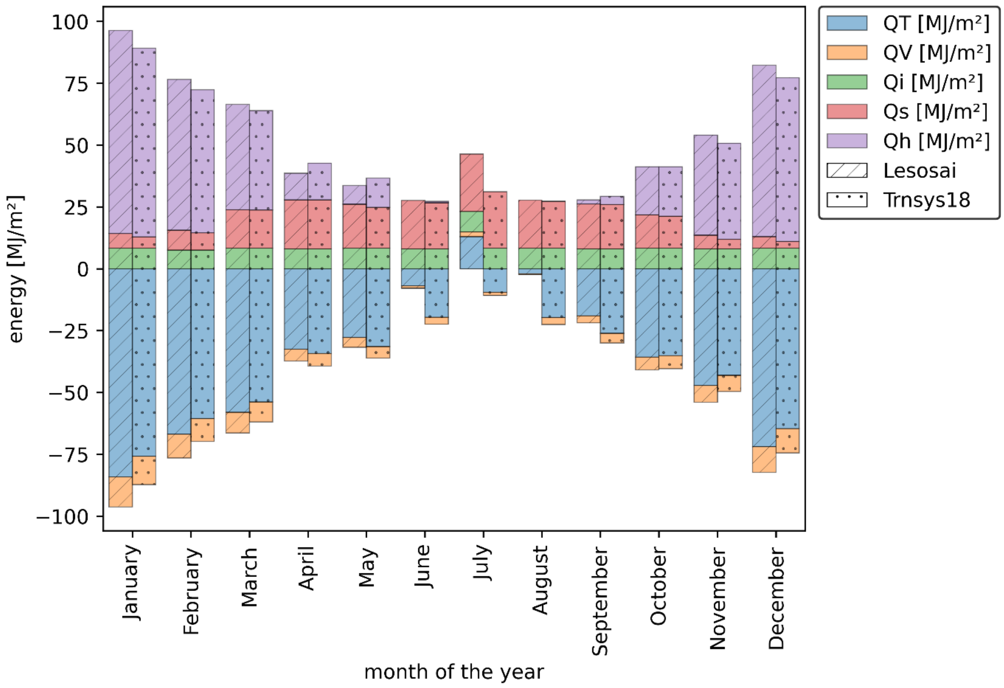



Figure 11: Monthly comparison of heat losses (QT, QV) and gains (Qi, Qs, Qh) in MJ/m² for the 'Gros-Chêne' building between the LESOSAI monthly balance and the TRNSYS18 simulation results over a whole year. Hatched bars represent the TRNSYS18 results, while dotted bars represent the LESOSAI results.

Table 7: Monthly and annual relative differences in heat losses (QT, QV) and gains (Qi, Qs, Qh) for the 'Gros-Chêne' building between the LESOSAI monthly balance and the TRNSYS18 simulation results.

| Period | Transmission losses $\delta Q_T$ | Ventilation $\delta Q_V$ | Internal gains $\delta Q_i$ | Solar gains $\delta Q_s$ | Space heating $\delta Q_h$ |
|---|---|---|---|---|---|
| **January** | 10.0% | 5.2% | -0.1% | -22.6% | -7.1% |
| **February** | 9.4% | 4.6% | -0.2% | -12.6% | -5.1% |
| **March** | 7.2% | 2.6% | -0.1% | -0.5% | -5.9% |
| **April** | -5.2% | -8.4% | 0.3% | -0.1% | 37.7% |
| **May** | -13.1% | -16.4% | -0.1% | -7.3% | 57.6% |
| **June** | - | - | - | - | - |
| **July** | - | - | - | - | - |
| **August** | - | - | - | - | - |
| **September** | -36.9% | -37.1% | 0.3% | -1.4% | 105.6% |
| **October** | 1.9% | -2.8% | -0.1% | -4.0% | 3.0% |
| **November** | 8.6% | 4.3% | 0.3% | -30.4% | -3.9% |
| **December** | 10.2% | 4.9% | -0.1% | -41.2% | -4.6% |
| **Year** | **-7.8%** | **-12.3%** | **-0.0%** | **-5.9%** | **-1.5%** |

# 4 Space heating and DHW system

The project aims at evaluating the effect of envelope retrofitting and system optimization measures on the system production and distribution supply/return temperatures. To do so, we selected several systems, since the impact of the retrofitting/optimization measures will most likely depend on the type of system. This chapter first outlines the selected SH and DHW systems, then it describes the heat emitters and associated heating curves, and finally presents the energy model developed for one of the SH/DHW systems (an air-source HP system).

## 4.1 Selected SH and DHW systems

The selected SH and DHW systems are illustrated in Figure 12. They correspond to two categories: systems for buildings connected to a DHN, i.e. DHN substations (SST), and systems for buildings equipped with their own heat generator. Since the main renewable energy source in dense urban areas is the air, we only consider air-source heat pump system (ASHP), but other type of systems could be implemented in some cases, depending on the resource availability and local restrictions (e.g. ground-source heat pump system, PV/T collectors,…).

These systems correspond to the most common configurations found in existing systems, and the most promising architectures regarding temperature levels. The aim is to first identify the pros and cons of each system in terms of temperature levels via numerical simulations, and then to determine the most promising optimization measures for each one of them.

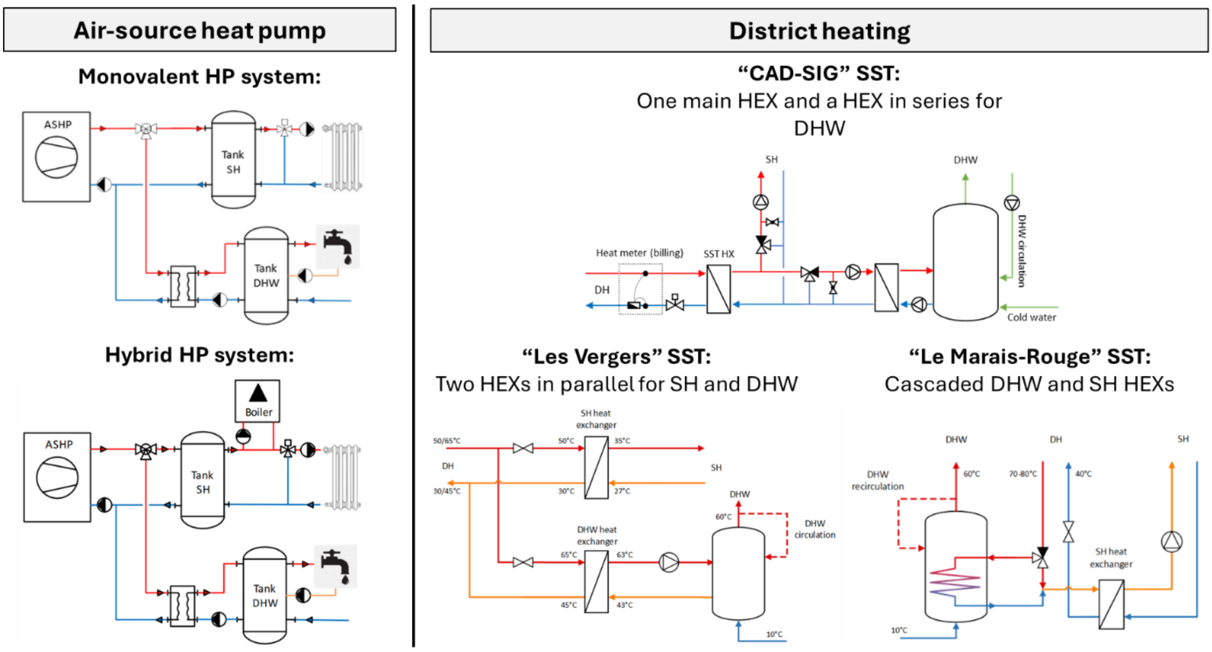



Figure 12: Selected SH and DHW systems

### Air-source heat pump systems

At the building level, the study will focus on air-source HPs, with or without backup heater. Indeed, hybrid HP systems with gas boilers can significantly reduce $CO_2$ 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, insufficient capacity of the electrical grid,…). It can also limit peak power usage in winter.

Case studies on several ASHP systems installed in large existing buildings have been analyzed [7] and will be used as comparison for system sizing, control strategies, as well as energy model inputs and validation.

**District heating substations**

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 12) 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:

- "CAD-SIG" SST [32]: It consists in one main heat exchanger, followed by another heat exchanger in series for DHW preparation and direct SH. Due to the two heat exchangers in series for DHW, this architecture tends to result in high return temperatures from the DHW system to the DHN. Moreover, it requires higher supply temperatures from the DHN than architectures with one heat exchanger between the DHN and the DHW storage tank. It is commonly found in existing old DHN in Switzerland, such as Geneva's main DHN "CAD-SIG" and Lausanne's main DHN. Operators of both DHN are planning to reduce the supply and return temperatures of the network in the upcoming years/decades.
- "Les Vergers" SST [33]: It consists in two heat exchangers in parallel, one for SH and one for DHW preparation. In principle, it is easier to control and optimize than the "CAD-SIG" SST architecture, in particular because both heat exchangers can be sized separately based on their respective constraints.
- "Le Marais-Rouge" SST [32]: It consists in cascaded DHW and SH heat exchangers. It is an innovative substation architecture, designed to minimize the impact of the DHW preparation on the SST return temperatures.

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), in particular for DHW preparation.

Case studies on each one of these SST architectures installed in large existing buildings have been analyzed [32,33] and are used as comparison for system sizing, control strategies, as well as energy model inputs and validation.

Energy modeling will primarily be performed using the TRNSYS software [24], which enables integrated modeling of buildings and SH/DHW systems on an hourly or sub-hourly timescale.

## 4.2 Heat emitters and heating curves

The building space heating demand is covered via heat emitters. To be able to capture the dynamic of SH supply and evaluate the effect of retrofitting and optimization measures on distribution temperatures, the heat emitters are simulated within TRNSYS, and coupled with the RC model described in section 3.3. It is a compromise between a simple building modeled with an energy signature, which does not take into account interactions between the building and the distribution system in terms of temperature levels, and a detailed multizone building model (e.g. EnergyPlus, TRNSYS Type56, etc.), which would include the simulation of a heat emitter in each zone but is a time consuming process.

The SH distribution system model is characterized by several parameters: the installed heat emitters capacity, the supply/return fluid temperatures and the flow rate. These parameters vary from one building typology to another, and depend on the optimization measures implemented in the system. The heat emitters are modeled in TRNSYS using Type362 [34], a dynamic radiator model accounting for the capacitance of the radiator.

## Installed heat emitters capacity

For each building typology, we initially consider that the installed heat emitters capacity remains unchanged after envelope retrofitting, matching the capacity installed when the building was initially built (non-retrofitted building). The methodology for calculating the installed heat emitters capacity is detailed in Appendix 10.2.

Several studies have highlighted the benefits of replacing critical radiators to lower the supply/return temperature, rather than replacing all radiators [14,35]. Furthermore, new technologies of radiators are now available, such as low-temperature radiators with active ventilation [36]. Therefore, subsequent analyses in this project may explore optimization scenarios to evaluate the impact of either replacing critical radiators (i.e. increasing installed radiator capacity) or replacing the existing radiators with low-temperature radiators to reduce the required supply temperature for SH.

## SH supply and return temperatures

Several supply/return temperature scenarios are considered for this project: i) a baseline scenario, representing the most common conditions observed in existing buildings, and ii) optimized heating curve scenarios to evaluate the potential for lowering the SH distribution temperatures.

Heating curves for the baseline scenario are based on a study of SH distribution temperatures in 68 buildings in Geneva [37], encompassing various typologies, construction periods and heat demand. It has shown that the supply/return temperatures for buildings equipped with radiators are remarkably consistent from one building to another. These temperatures show minimal dependence on the building's SH load or construction period. The heating curves derived from this study (Figure 13) will serve as baseline scenario.

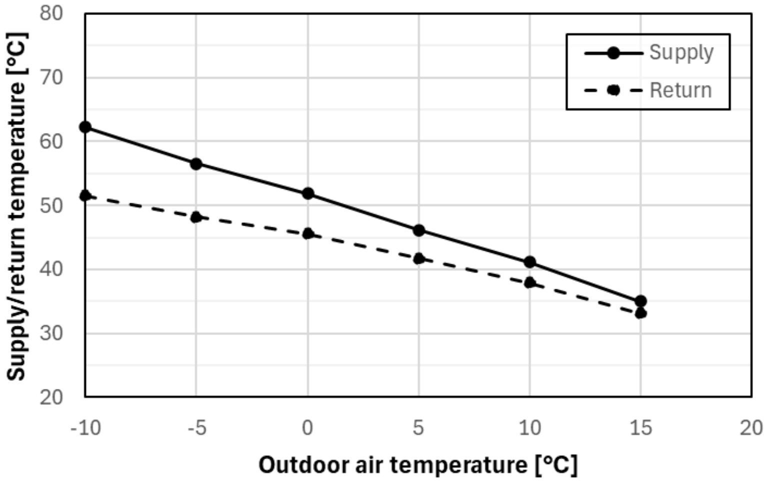



Figure 13: Heating curves for the baseline scenario, taken from median values for radiators systems in [37]

Several studies conducted in Denmark, UK and Germany [14,38–40] have demonstrated that heat emitters are often oversized relative to the building's SH demand. As a result, supply/return temperatures can potentially be reduced compared to the heating curves typically observed.

The most common optimization approach involves lowering the supply temperature as much as possible. This increases the distribution flow rate to meet the same space heating (SH) load but also raises the return temperature. For buildings supplied by heat pumps, this method enhances the HP COP, as the COP increases as the supply temperature decreases.

However, studies [41–43] suggest that for buildings supplied by district heating networks (DHNs), it is more beneficial to minimize the SH return temperature rather than the supply temperature. This approach, known as the "low-flow" method, reduces the SH distribution flow rate while increasing the supply temperature to meet the SH demand. Consequently, it lowers the building's SH return temperature, which in turn reduces the DHN substation return temperature. This method is particularly interesting when the DHN supply temperature is relatively high and cannot be further reduced, such as Geneva's main DHN (CADSIG-CADIOM) which supply temperature will be reduced to 90°C by 2035. By lowering the return temperature of the DHN, renewable energy integration in the DHN mix is maximized, and the DHN distribution capacity is increased. In the case of building supplied by a HP rather than a DHN, this method would negatively impact the HP efficiency, as higher supply temperatures are required.

Two main heating curve optimization methods are thus identified:

1) The "low-flow" method, better suited for DHN-supplied buildings, which minimizes the return temperature but results in higher supply temperatures.
2) The "high-flow" method, preferable for buildings using heat pumps, which minimizes the supply temperature but requires a higher flow rate in the distribution system.

Figure 14 illustrates an example of optimized heating curves for a partially retrofitted building. The details for the calculation of these optimized heating curves are presented in Appendix 10.2.

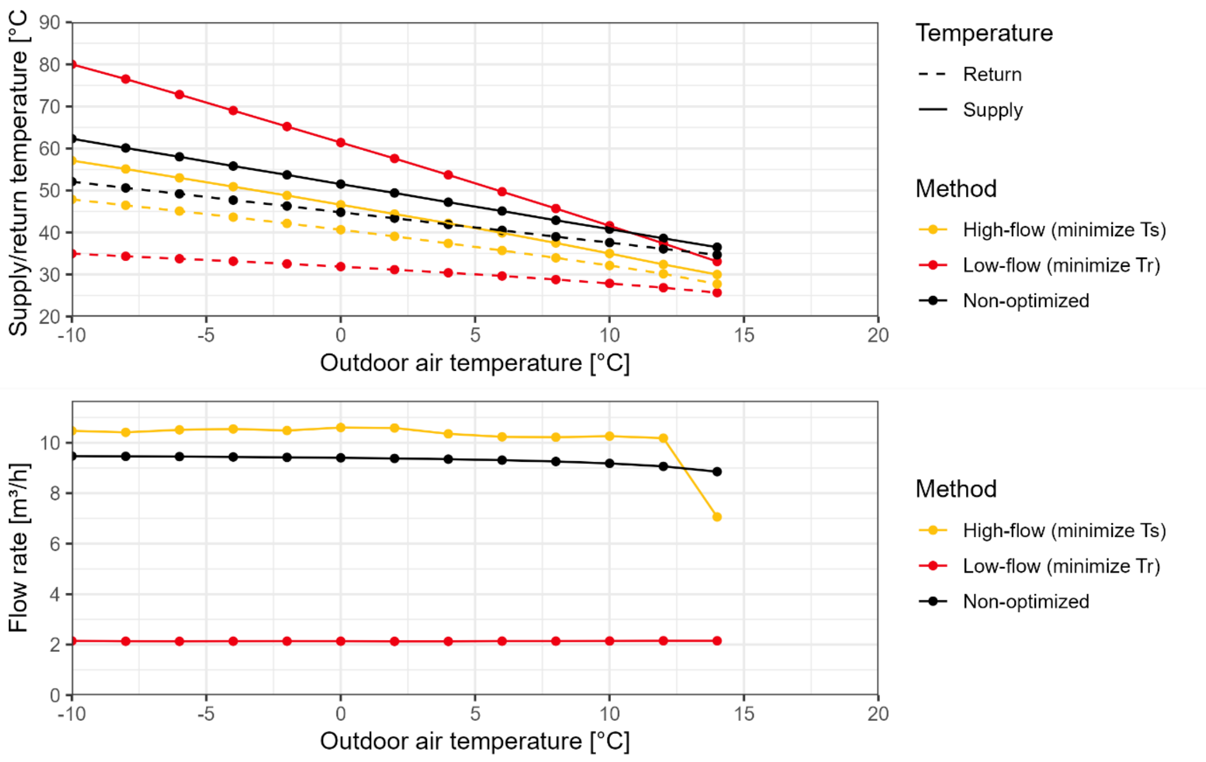



Figure 14: Non-optimized heating curve (baseline) and optimized heating curves using the "low-flow" and "high-flow" methods for building typology TypoReno G3 [20] partially retrofitted (step 2)

## 4.3 Air-source HP model

The first SH/DHW system implemented in TRNSYS is an air-source HP system with backup heater (Figure 15). It is partially based on the model developed in the AirBiVal project [44], which was validated on a monitored SH/DHW system. It is simulated with a timestep of 1 minute. Key information on the system components, sizing and control strategy are described below.

It should be noted that the following description corresponds to a system with a HP sized to meet 100% of the SH and DHW load (i.e. monovalent system), where the backup heater is solely used to ensure comfort during peak load. However, the same model could be used with different HP and backup heater sizing to simulate hybrid HP systems, in which the backup heater covers a larger share of the heat demand.

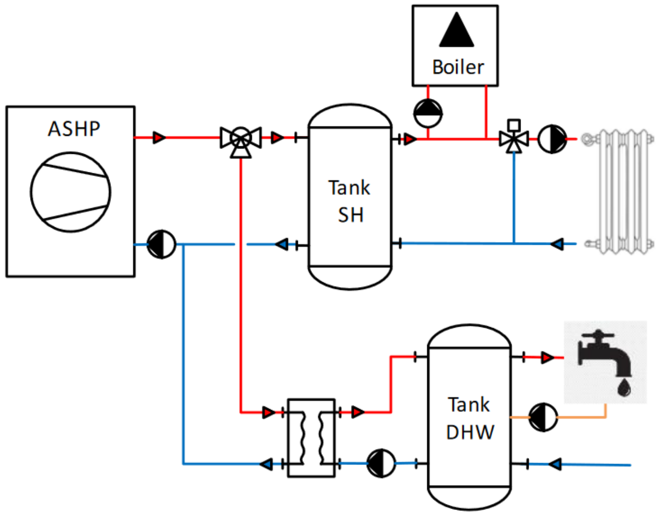



Figure 15: Schematic diagram of the air-source heat pump system with backup heater for SH

### Weather

Weather conditions, including outdoor air temperature and solar irradiation, are based on hourly values from SIA 2028 standard [45] for an average year in Geneva (2'820 $HDD_{18}$; global horizontal radiation: 1'277 kWh/m²/year), representative of the Swiss Plateau.

Following advisory board recommendations, future simulations will use 2035 weather projections [46] (2'546 $HDD_{18}$; global horizontal radiation: 1'234 kWh/m²/year) to better estimate SH demand under projected climate conditions.

### Building

The building is simulated using the RC building model (TRNSYS Type 5897) [29] described in section 3.3. Building envelope parameters are sourced from the LESOSAI energy models for the desired building typology and retrofitting state.

### Space heating

- **Load:** Space heating is supplied to the building via radiators (TRNSYS Type 362 [34]) that calculate heat output and fluid outlet temperature based on heat emitters capacity, inlet fluid temperature, flow rate, and building indoor temperature. Heat emitters are sized as described in section 4.2.
- **Control strategy:** Heat is supplied to the distribution loop by the HP, via a buffer tank maintained at a temperature range defined by the heating curve (+ 5 K). An electric backup heater ensures the SH loop supply temperature does not fall below a setpoint (heating curve – 2 K). This may be necessary because the SH buffer tank volume, primarily meant for hydraulic separation and HP short-cycling prevention, is insufficient to cover SH loads during SH peak loads or DHW production cycles. Return flow is mixed with buffer tank output to match the supply temperature setpoint if needed. The SH pump modulates the distribution flow rate to maintain the indoor temperature setpoint. If the indoor temperature reaches the setpoint temperature but the SH pump is already operating at its minimum flow rate, it will maintain this flow rate and only shut off if the indoor temperature exceeds the setpoint by 1.5 K. Additionally, SH is completely switched off from June 1 to October 1.

- **Sizing:** The SH buffer tank is sized at 10 L/kW$_{th}$ of HP capacity (as observed on several case studies, e.g. [44]). The distribution pump is sized to meet the setpoint supply/return temperature difference for the SH load at an outdoor temperature of -10°C.

**Domestic hot water**

- **Load:** DHW demand is modeled using an hourly tapping schedule from the SIA 385/2 standard for multifamily buildings, with a constant cold-water inlet temperature of 10°C. The daily DHW tapping volume is equal to 50 L/day per occupant, assuming 40 m$^2$/occupant.
- **Control strategy:** Heat is supplied to the DHW tank by the HP via an external heat exchanger (80% efficiency). The DHW tank is maintained at 50–60°C based on a sensor placed in the upper third of the tank. The circulation pump on the load side operates when there is a DHW demand.
- **Sizing:** Tank sizing follows the SIA 385/2 standard [47], assuming 6 one-hour DHW cycles per day, 45 L/day per occupant, and 40 m$^2$/occupant. The circulation pump between the heat exchanger and the tank is sized for a temperature difference of 7.5 K.

**Heat pump and backup heater**

- **Control strategy:** The HP switches between SH and DHW production to maintain the tanks at their respective setpoint temperatures. In the case of a simultaneous demand, priority is given to DHW. The backup heater is activated to maintain the supply temperature above the setpoint minus 2 K, as needed.
- **Sizing:** The HP is sized to meet 100% of the heat demand in SH and DHW in monovalent operation:
    - **SH:** The HP is designed to meet SH peak demand within 18 hours, reserving the remaining 6 hours for DHW cycles, with production temperature of 55°C and an outdoor temperature of -10°C. Following advisory board recommendations, future simulations will use a design temperature of -4°C as per SIA 2028 (Table 1 in [48]).
    - **DHW:** The HP is sized according to SIA 385/2 standard [47] assuming the same conditions used for DHW tank sizing, explained above, and a production temperature of 65°C at an outdoor temperature of -10°C.

  After following the above sizing procedure separately, the higher of the two capacities (SH/DHW) is finally selected.
- **Energy performance:** HP COP and heating capacity are derived from manufacturer data [49], as a function of the outdoor air temperature (source) and the condenser inlet temperature (load).

# 5 Integrated building and SH/DHW system

In the last part of the study, actions identified are combined in various scenarios, representing different levels of system optimizations and retrofitting depth (partial to full). As illustrated on Figure 16, using integrated simulation, we explore the impact on energy, economic and environmental performance indicators to identify the most cost-effective scenarios according to the building (section 3.1) and SH/DHW system (section 4.1) typologies.

This chapter first presents the performance indicators identified to compare the different scenarios and assess the impact of the retrofitting/optimization measures on the system production/distribution temperatures, efficiency, integration of renewable energy and decarbonization. Then, it shows the simulation results for a baseline scenario: a non-renovated building supplied by an ASHP system. Finally, it presents the method to define sensitivity analysis scenarios with the implementation of various envelope retrofitting measures and heating curves optimization.

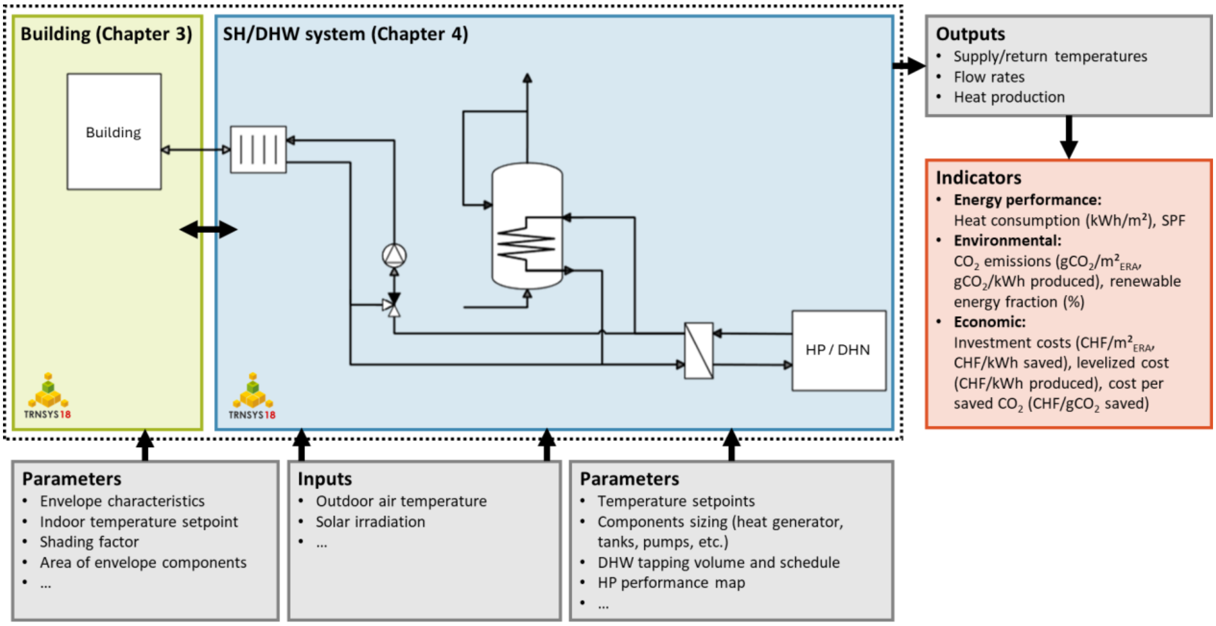



Figure 16: Schematic representation of the integrated building and SH/DHW system model

## 5.1 Performance indicators

Several performance indicators are identified to evaluate the impact of the retrofitting and optimization measures on the system.

### Temperature levels

The first indicators are the annual heat-weighted average temperatures (supply/return/DT) at different locations in the system (Figure 17). The most important temperatures being the production temperatures (HP condenser or SST primary side supply/return temperatures) since the efficiency of the heat generator and the integration of renewables in the system depend on them. Nonetheless, the other temperatures will allow to identify the strengths and weaknesses of each type of system in terms of temperature levels, which will in turn allow to target the most promising optimization measures for each system.

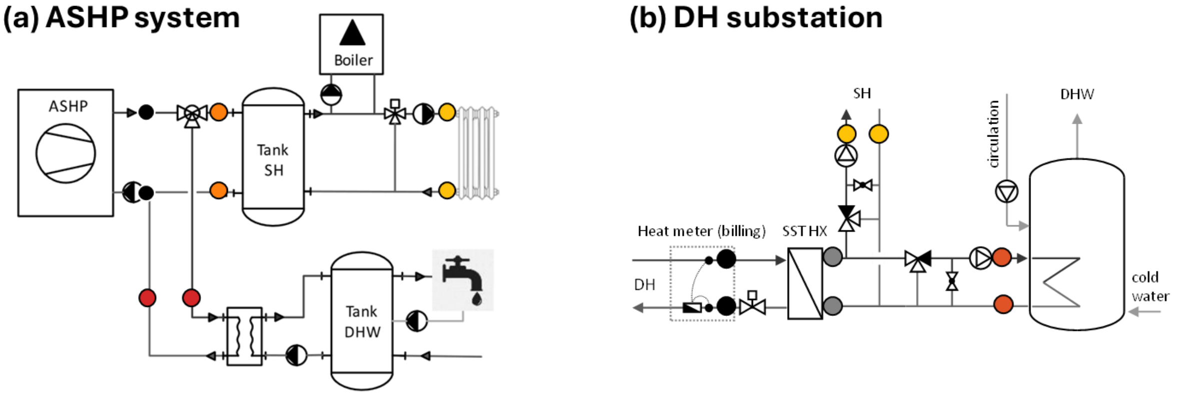



Figure 17: Locations in the system for the evaluation of annual average temperature levels

### Energy performance

The energy performance of the system is first evaluated with the specific heat demand (SH and DHW, in kWh/m²). Then the impact of the lowered temperature levels on the heat production efficiency is assessed with the seasonal performance factor of the HP ($SPF_{HP}$), calculated according to Equation (1). It is defined as the ratio of annual heat production ($Q_{HP}$) to annual HP electricity consumption ($E_{HP}$).

$$SPF_{HP} = \frac{Q_{HP}}{E_{HP}} \tag{1}$$

To account for the heat production ($Q_{backup}$) and energy consumption ($E_{backup}$) of the backup heater, we calculate the seasonal performance factor of the system ($SPF_{system}$) as per Equation (2), including the heat production and energy consumption of both the HP and the backup heater.

$$SPF_{system} = \frac{Q_{HP} + Q_{backup}}{E_{HP} + E_{backup}} \tag{2}$$

These two SPF do not take into account the electricity consumption of the system auxiliaries (circulation pumps, controllers, etc.).

For buildings supplied by DHN, the efficiency of the heat generator will depend on the energy sources for the DHN and will be defined in the next part of the project.

### Environmental performance

The environmental performance of the ASHP system before and after implementation of retrofitting/optimization measures is evaluated in terms of decarbonization, using the $CO_{2eq}$ emissions related to the operation of the heat generators (ASHP and backup heater), as well as renewable energy integration, with the renewable energy fraction of the heat production.

Emissions related to the electricity consumption are calculated using Equation (3), where $E_{HP,h}$ and $E_{backup,elec,h}$ correspond respectively to the ASHP and backup heater electricity consumption. The hourly emission factor of the electricity ($f_{elec.h}$ in $kgCO_{2eq}/kWh_{elec}$) is based on the hourly $CO_{2eq}$ content of the Swiss electricity mix from the work of Romano et al. [50], taking into account domestic generation as well as imports from neighboring countries. Since the system is modeled for a typical year rather than an actual year, we use the hourly average of years 2017-2021. The annual average is equal to 96 $gCO2eq/kWh_{elec}$, but daily peak values reach up to 200-300 $gCO2eq/kWh_{elec}$ (see Appendix 10.2 for the whole profile).

$$C_{grid} = \sum_{h} (E_{HP,h} + E_{backup,elec,h}) \cdot f_{elec.h} \tag{3}$$

If the backup heater is a gas-fired boiler rather than an electric boiler, emissions related to its heat production are calculated using Equation (4), with a constant emission factor ($f_{gas}$) equal to 230 $CO_{2eq}$/kWh$_{th}$ [51]. Finally, the total emissions of the system are evaluated using Equation (5).

$$C_{gas} = E_{backup,gas} \cdot f_{gas} \tag{4}$$

$$C_{system} = C_{grid} + C_{gas} \tag{5}$$

Total emissions are then divided either by the building ERA, to provide an indicator of the carbon emissions intensity of the building (in kg$CO_{2eq}$/m² of ERA), or by the heat demand/produced, to evaluate the efficiency of the system in terms of emissions (in kg$CO_{2eq}$/kWh$_{th}$).

Note that we only consider emissions related to the energy consumption of the heating system. Embodied energy of the building retrofit and the system (e.g. heat pump, etc.) is not included.

For the ASHP system, as described in Equation (6), the annual renewable energy fraction ($\%Ren$) corresponds to sum of the energy extracted from the air ($Q_{air}$) and the renewable energy from the electricity mix ($E_{elec,ren}$), divided by the total amount of heat produced by the ASHP and the backup heater. The renewable energy from the electricity consumption ($E_{elec,ren}$) is assessed with Equation (7), where $\%Ren_{elec,h}$ is the hourly Swiss electricity share produced by primary energy originating from renewable sources, according to the work of Romano et al. [50] (as hourly average for years 2017-2021).

$$\%Ren = \frac{Q_{air} + E_{elec,ren}}{Q_{HP} + Q_{backup}} \tag{6}$$

$$E_{elec,ren} = \sum_{h} (E_{HP,h} + E_{backup,elec,h}) \cdot \%Ren_{elec,h} \tag{7}$$

For buildings supplied by DHN, the calculation of the $CO_{2eq}$ emissions and renewable energy fraction will depend on the energy sources for the DHN and will be defined in the next part of the project.

**Economic performance**

To evaluate the cost-effectiveness of the retrofitting/optimization measures, two main indicators have been defined: i) the investment cost necessary for the implementation of the envelope retrofit and system optimization measures (in CHF/m² ERA), and ii) the total annual cost, which accounts for both the investment cost and the energy cost (in CHF/m² ERA). The investment cost for envelope retrofit is taken from the building typology sheets from the TypoReno project [20].

Other economic indicators will be defined later on in the project to compare the scenarios, for example the levelized cost (in CHF/kWh prod), the cost per saved $CO_{2eq}$ (in CHF/kg$CO_{2eq}$ saved) or the cost per temperature gradient (in CHF/°C) to evaluate the effectiveness of the measures in terms of temperature levels reduction.

## 5.2 Baseline scenario

The first integrated building and SH/DHW system simulation is done for the non-renovated TypoReno G3 building [20] supplied by an ASHP system, with an electric backup heater for SH. The main hypothesis for the energy modeling (component sizing, control strategy, etc.) are described in section 3.2 for the building, section 4.2 for the heat emitters and section 4.3 for the ASHP system. This section presents the results for the indicators described in section 5.1.

Pending the final selection of building typologies for this project, building typology TypoReno G3 was chosen to obtain preliminary results for several reasons: i) as described in Chapter 3, step-by-step envelope retrofitting scenarios are available with current investment costs, and ii) although it does not represent a predominant building typology in the MFB stock, it corresponds to one of the eRen typologies (eRen sheet No3). In the next phase of the project, a baseline building typology will be chosen from the selected typologies.

### System parameters

The main parameters of the baseline ASHP system are summarized in Table 8.

Table 8: Summary of the main parameters in the baseline ASHP system

| Type | Parameter | Value |
|---|---|---|
| **Building** | Building typology | TypoReno G3 |
| | Envelope retrofitting stage | non-renovated |
| | Energy reference area (ERA) | 2'445 m² |
| | Indoor temperature setpoint | 21°C |
| **Heat generation** | Heat pump capacity | 195 kW at A7/W35 |
| | Backup heater capacity | 40 kW |
| **Space heating** | SH demand | 102 kWh/m².year (367 MJ/m².an) |
| | Volume of SH tank | 2.0 m³ (10 L/kW$_{th}$ HP) |
| | Maximum distribution flowrate | 9.6 m³/h |
| **Heat emitters** | Radiator capacity | 56 W/m² at 62/51/20°C (84 W/m² at 75/65/20°C, EN442 standard) |
| | Radiator oversizing factor (compared to SH demand at -10°C) | 120% |
| | Heating curve | non-optimized (as per benchmark, see Figure 13) |
| **DHW** | Number of occupants | 61 (40 m²/occ) |
| | Daily tapping volume | 50 L/occ.day |
| | Volume of DHW tank | 1 m³ |

### Temperature levels

Since the project focuses on the temperature levels, it is interesting to confirm that the simulated temperatures correspond to the temperatures observed in practice. Figure 18 shows the simulated supply and return temperatures from the heat emitters, alongside the heating curves measured in existing buildings from [37] (Figure 13).

Except for some rare cases, the supply temperature follows the heating curve set as input to the controller. However, the return temperature is much lower than observed in the measures. This is most likely due to a lower distribution flow rate in the simulation than in the measured systems (the lower the flow rate, the higher the temperature difference), which could indicate that the flow rate of the pumps in the measured systems is too high. It would be interesting to restrict the flow rate in the baseline to higher flow rates to obtain simulated return temperatures closer than the temperatures measured in existing buildings.

The minimum return temperature in the simulation corresponds to the operation of the SH loop at the minimum flow rate, i.e. when the indoor building temperature is close to or higher than the setpoint. At that time, the pump controller therefore lowers the flow rate to reduce the amount of heat supplied to the building and therefore prevent overheating.

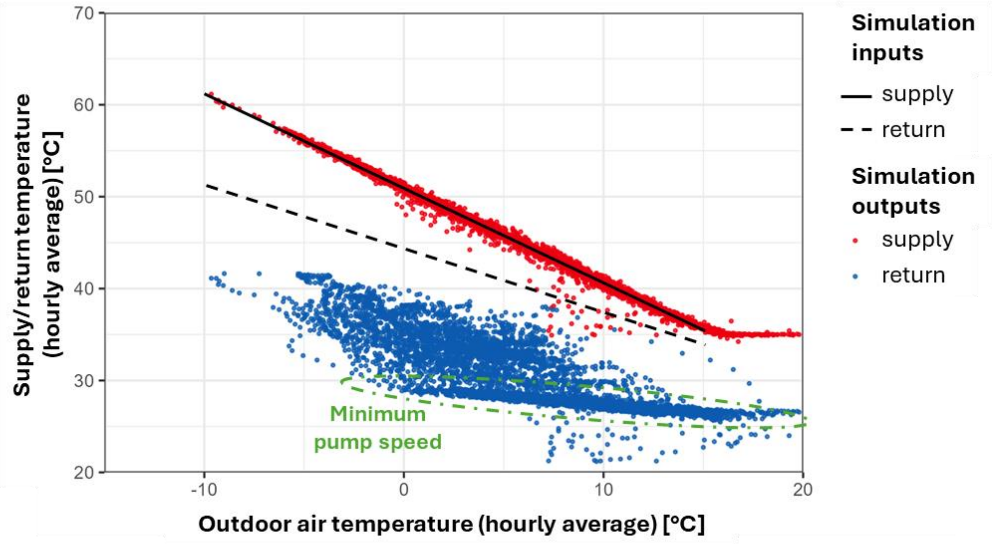



Figure 18: Hourly simulation results for the SH distribution supply/return temperature (inlet/outlet temperature of the heat emitters) and baseline heating curves from [37] (Figure 13), used as input to the model.

On average (heat-weighted) over the entire year, these distribution-side SH supply/return temperatures are equal to 46/33°C, as shown in Figure 19. The production-side SH temperatures are slightly higher (47/43°C) because, as explained in section 4.3, the HP maintains the SH buffer tank at the supply temperature setpoint given by the heating curve, with a hysteresis of +0K to +5K. Since the HP operates with a supply/return temperature difference of approximately 5K, the average return temperature is about 5K lower than the supply temperature. The average HP supply/return temperatures (50/45°C) are a few degrees higher than the SH production temperatures, due to the DHW production temperatures (56/51°C), which are high to prevent legionella proliferation. Since the DHW demand accounts for a relatively small portion of the total heat demand (30%, see Figure 20), the higher DHW temperatures have a limited impact on the average HP production temperatures. However, this influence would be more significant for buildings with lower SH demand.

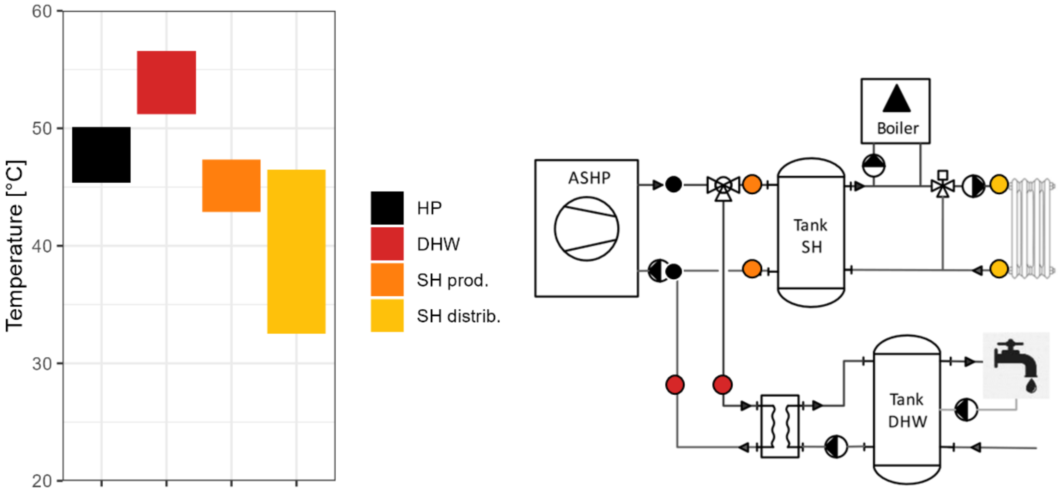



Figure 19: Annual average (heat-weighted) supply/return temperatures in the system. Each bar represents the average supply temperature (top), return temperature (bottom), and their difference (bar height).

### Energy balance

The energy balance results for the baseline scenario are presented in Figure 20 (annual results) and Figure 21 (daily results).

The annual heat production is predominantly covered by the HP, meeting 98% of the demand, with the remaining 2% supplied by the backup heater. Daily results reveal that the backup heater is only activated during peak SH demand in the winter. This occurs because the volume of the SH buffer tank is insufficient to cover the SH load while the HP is producing DHW (as described in section 4.3, the HP switches between SH and DHW production, with priority given to the DHW production).

The annual SPF of the HP is equal to 2.71, but the SPF fluctuates on a daily basis throughout the year. It drops to approximately 2.0 during the winter peak SH demand, when the HP operates at its lowest COP and the backup heater is needed. In contrast, it rises to about 3.8 during summer, due to high outdoor air temperature which improve the HP COP, even with high DHW production temperatures. On an annual basis, the SPF for DHW production alone is equal to 2.88, and 2.80 / 2.63 for SH production (with/without backup electricity consumption). The higher SPF for DHW production than for SH production reflects the high SPF during the summer months, as well as the non-optimized heating curve and relatively high SH production temperatures required for the non-renovated building. Additionally, the use of the backup heater significantly reduces the SPF for SH, despite its minor contribution to the overall heat production. Since the backup heater has a significant impact on the system SPF, it will be further analyzed in the next phase of the project to minimize its usage while ensuring SH comfort.

The system generates 6.4 $kgCO_{2eq}/m^2_{ERA}$ annually due to its electricity consumption, with a renewable share of 79%. Emissions are lowest during summer due to the low heat demand and low $CO_2$ content of the electricity mix (see Appendix 10.2). During the winter, $CO_2$ emissions of the system are significantly higher, reflecting the higher heat demand and a smaller share of renewable energy in the electricity mix.

It is interesting to note that the system delivers a small excess of SH (11 MJ/m².year). It is attributed to mid-season operation, during which the SH distribution pump continues operating at its minimum flow rate even after the indoor temperature has exceeded the 21°C setpoint, only stopping when the temperature reaches 22.5°C (as defined in the control strategy in section 4.3).

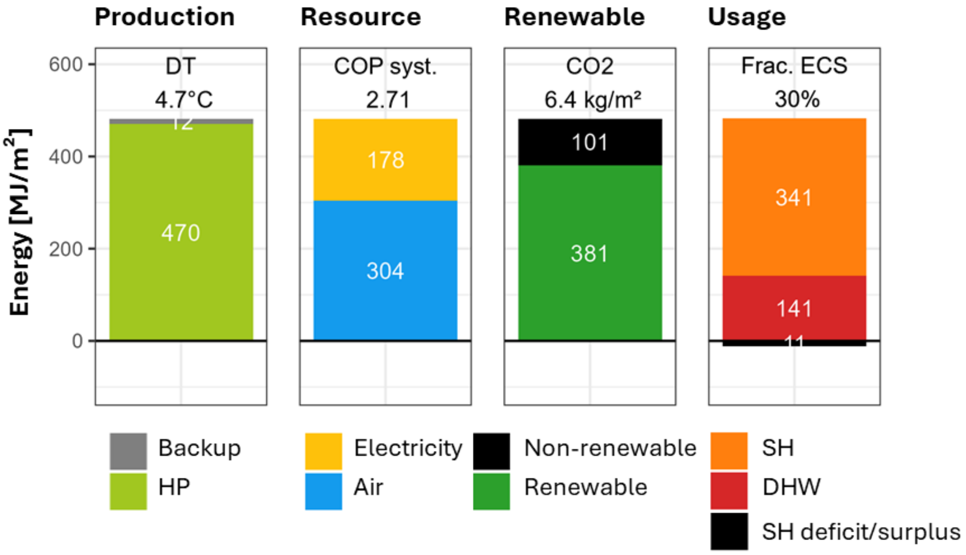



Figure 20: Annual simulation results for the baseline scenario of the ASHP system for building typology TypoReno G3 (non-renovated)

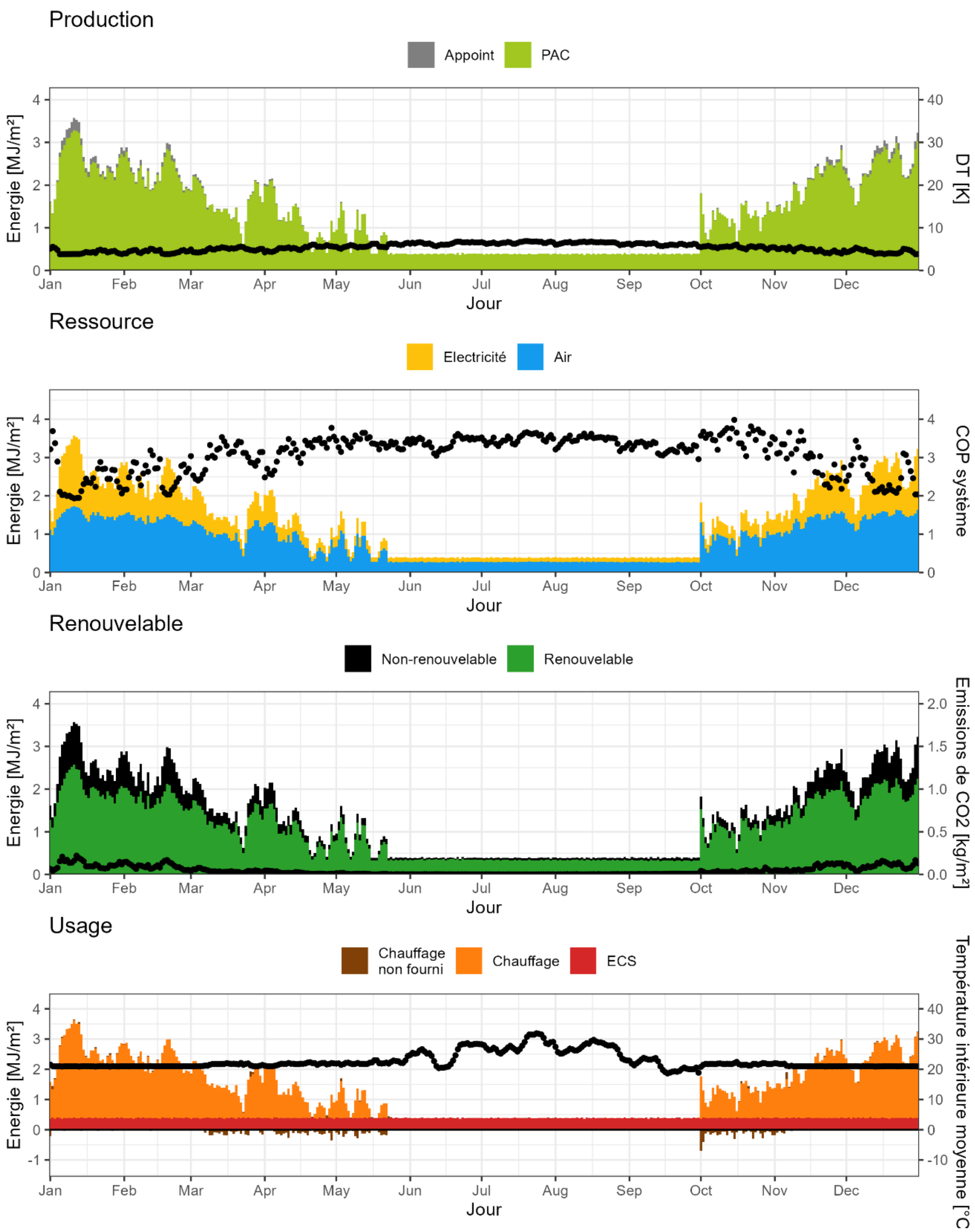



Figure 21: Daily simulation results for the baseline scenario of the ASHP system for building typology TypoReno G3 (non-renovated)

## 5.3 Sensitivity analysis

A sensitivity analysis on the system will be performed in the next part of the project. It will consist in combining targeted envelope retrofitting measures to SH/DHW system optimization measures for different building and SH/DHW system typologies, as illustrated in Figure 22.

For each building typology and envelope retrofitting scenario, the building envelope parameters will be taken from the LESOSAI model. Then, it will be implemented into Type 5897 (RC building model, see section 3.3) in TRNSYS with an ideal SH system to produce the daily SH demand and generate the building energy signature. This can be done to analyze various building typologies and envelope retrofitting measures, but also different indoor temperature setpoints.

The building energy signature can then be used for two purposes: i) optimize the heating curves based on one of the methods described in section 4.2, and ii) size the components of the system (heat pump, circulation pumps, etc.) based on the SH load at design outdoor air temperature.

Several SH/DHW system scenarios will be analyzed, for various system typologies (ASHP systems and DH substations described in section 4.1) as well as for the implementation of various system optimization measures (heating curves optimization, critical radiators replacement,…). These optimizations measures will be defined for each system typology based on their strengths and weaknesses in terms of temperature levels, as well as discussions with professionals.

Finally, the resulting building and SH/DHW system models will be combined to produce different scenarios and evaluate the impact the retrofitting and optimization measures on the performance indicators defined in section 5.1.

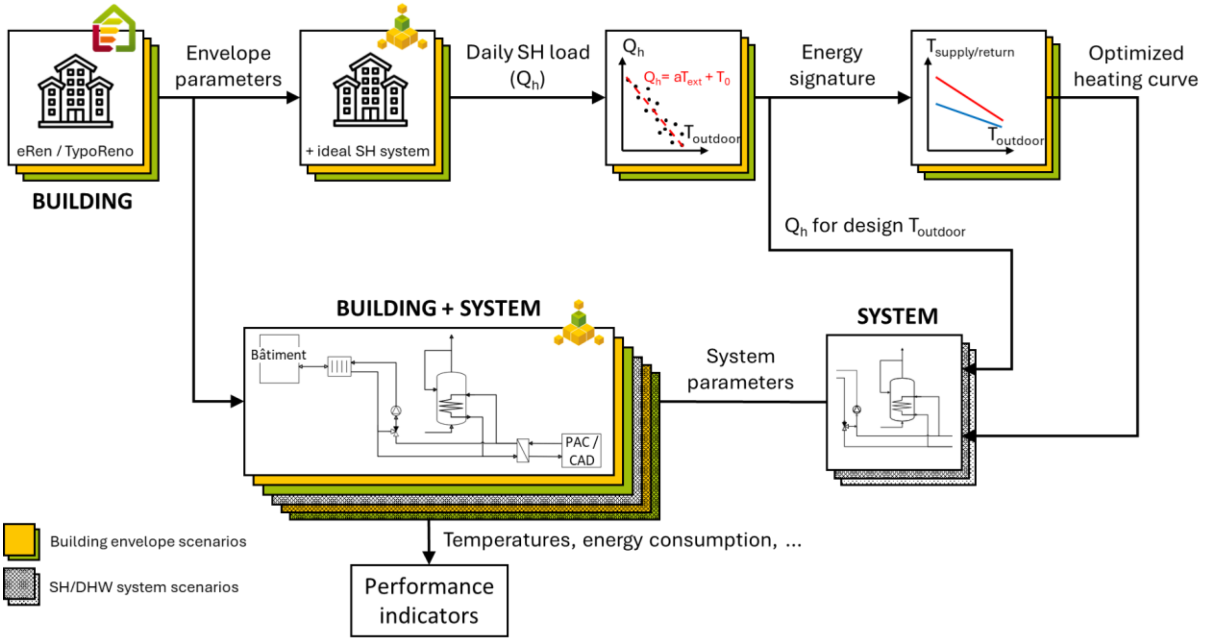



Figure 22: Methodology for the definition of sensitivity analysis scenarios for various building typologies and envelope retrofitting measures, as well as various SH/DHW system typologies and optimization measures

# 6 Conclusions and outlook

## 6.1 Conclusions

The T-DROP project aims at reducing production and distribution temperatures levels of SH/DHW systems, for multifamily buildings located in dense urban areas, for massive integration of renewables and decarbonization with heat pumps and district heating. To do so, it explores optimal combinations of targeted envelope retrofit and technical optimization of SH/DHW systems.

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 focuses on the selection and modeling of various SH/DHW systems, as well as optimization or replacement measures. Finally, those numerical models of both building and SH/DHW system are combined to quantify the benefits on renewable heat integration and decarbonization of existing multifamily buildings (MFBs), based on the defined performance indicators.

**Building typologies and retrofitting**

To establish the building model and associated retrofitting scenarios, the first step consisted in selecting building typologies representative of the Swiss multifamily building stock, based on an analysis of the Canton of Geneva's multifamily building stock and discussions with architects. To limit the number of cases, it focused only on predominant MFB typologies in need of retrofitting.

Then, for each selected building typology, envelope retrofitting scenarios were defined using building typology sheets from the eREN project, for which LESOSAI models were available. Some adjustments had to be made to obtain targeted retrofitting scenarios rather than full building retrofit, and evaluate current investments costs for each measure.

Finally, the building envelope parameters were extracted from the LESOSAI models and implemented into a resistor-capacitor (RC) building model within TRNSYS. This allows to simulate the building SH demand on an hourly basis and integrate the building model with a heat emitter model. This integration is important for accurately capturing the dynamics of supply and return temperatures within the system. The RC building model was validated against both a LESOSAI model and monitoring data of an existing MFB. The results show a good match between the TRNSYS and LESOSAI models, as well as between the TRNSYS model and the monitoring data.

**SH/DHW systems**

Several SH/DHW systems were selected to represent the most common configurations found in existing systems, and the most promising architectures regarding temperature levels. These systems include both decentralized heat production using air-source heat pumps (ASHP) and centralized production through district heating (DH) substations. The aim is to evaluate the impact of temperature reduction on the integration of renewables and decarbonization for various SH/DHW system typologies.

The heat emission system was then characterized, including the definition of heating curves, as well as two methods for the optimization of these heating curves based on the type of heat generator in the system, the building space heating demand and the installed heat emitters capacity.

Finally, an energy model of one of the selected SH/DHW systems, an ASHP system, was developed in TRNSYS. This model integrates the building thermal model and the SH/DHW system into a single simulation framework.

**Integrated building and SH/DHW system**

In the last part of the study, several energy, environmental and economic performance indicators were defined to quantify the impact of the retrofitting and optimization measures on the renewable energy integration and decarbonization of the system. They were then calculated for a baseline scenario of an ASHP system supplying heat to a non-retrofitted building. Finally, the methodology for the definition of sensitivity analysis scenarios was presented, including the implementation of various envelope retrofitting measures and heating curves optimizations. This methodology will be applied in the next part of the project to explore different combinations of targeted envelope retrofitting and SH/DHW optimization measures.

## 6.2 Project next steps

The next steps of the study will be as follow:

- **Finalize the selection and characterization of building envelope retrofitting scenarios** based on the upcoming building typology sheets from the TypoReno project. This involves: i) validating the current step-by-step envelope retrofitting scenarios (section 3.2) with architects, particularly regarding the cost estimate of each measure, and ii) adapting or replacing existing scenarios for typologies for which TypoReno sheets will be available, which provide more accurate cost estimates and step-by-step retrofitting strategies specifically tailored to each building typology.
- **Integrate the RC building model with other developed TRNSYS SH/DHW system models** (e.g. “CAD-SIG” SST architecture, “Vergers” SST architecture, etc.) and conduct a sensitivity analysis. This analysis will allow to identify the strengths and weaknesses of each type of system and select the most promising retrofitting and optimization measures.
- **Define energy, environmental and economic indicators for building SH/DHW systems connected to DHN.** While several indicators have already been defined for the ASHP system, their calculation must be adapted for building SST to be able to evaluate the impact of reduced temperatures levels on the DHN heat production efficiency, renewable energy integration and costs.
- **Select and simulate the most promising measures 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 (see first intermediate report of the project [52]), as well as engaging discussions with project partners who are active in the field.
- **Combine various optimization and retrofitting scenarios and assess the impact on the performance indicators**. The scenarios will represent different levels of system optimizations and retrofitting depth (partial to full) and will allow to identify the most cost-effective scenarios according to the building and SH/DHW system typologies.
- **Evaluate the influence of building typology** on the strategy for reducing the production and distribution temperatures of the SH/DHW system.

# 7 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 [20], 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 are used in T-DROP to establish building typologies and define realistic envelope retrofitting measures. Conversely, 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.

The project members are also in contact with Dietrich Schmidt from Fraunhofer IEE regarding their new project "CoolDown" [53]. It focuses on the optimization of piped heat supply in existing buildings and efficient integration of renewable heat sources into the networks through secondary measures.

Furthermore, the advisory board of the T-DROP project includes stakeholders active in the field, with diverse areas of expertise. It ensures 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, Gautier Falize (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 heat pumps) as well as building retrofit, in particular for multifamily buildings.

# 8 Publications and other communications

The work conducted by the partners as part of this project has resulted in the following publications and communications:

- Pitch presentation of the project during the 23rd Brenet Status-Seminar on August 27, 2024
- Olivier Paltenghi's Bachelor thesis on the case study of two MFB in Lausanne in collaboration with Services Industriels de Lausanne (SIL). The objective of this thesis was to study the impact of various optimization measures for space heating distribution and envelope renovation on the performance of an ASHP system (including bivalent solution with gas boiler).

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# 10 Appendix

## 10.1 Building retrofit sheets for selected predominant typologies

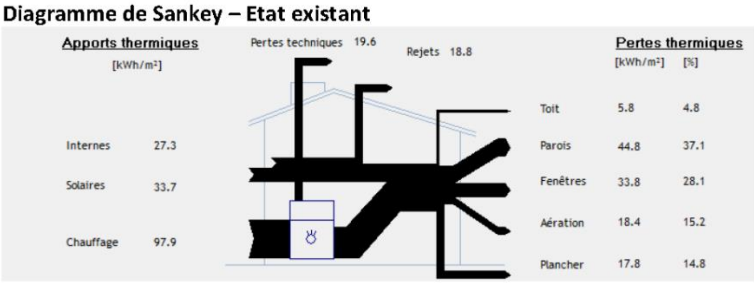
### Sheet for eREN No4 building typology

**eRen 4 – Levant 137**

**Modification par rapport à eRen :**
i. Méthode de calculs
ii. Station météorologique
iii. Adaptations mineures du bilan thermique existant

| | |
|---|---|
| Mode de calculs | SIA 380/1 :2016 |
| Station météorologique | Genève - Cointrin |
| Année de construction | 1960 |
| SRE [m²] | 1475 |
| Facteur de forme [-] | 1.1 |
| Besoin de chaleur limite [kWh/m²] | 44.3 |
| Coûts actualisé oct.2024 | eRen adapté IDC (base 100, oct.2015) |

**Diagramme de Sankey – Etat existant**




| Scénario de rénovation | Description | QH [kWh/m²] | Classe env. th | Puissance [W/m²] | Coûts unitaire* [CHF/m²SRE] |
|---|---|---|---|---|---|
| Etat existant | Sans vannes thermostatiques<br><br>Plancher des combles mis d'origine (non isolé)<br><br>Fenêtres d'origine (Ug=3, Uf=1.9, psi=0.07) | 116.3 | G | 45,7 | |
| Etat existant | Avec vannes thermostatiques | 94.7 | G | 42.2 | |
| Fenêtres | Selon eRen + psi 0.04 | 79.1 | F | 35.7 | 206 |
| Combles | Selon eRen | 75.6 | F | 35.7 | 87 |
| Façade, stores+Blacons | Selon eRen | 68.5 | E | 32.4 | 569 |
| Fenêtres+ combles | | 60.2 | E | 28.2 | 293 |
| Fenêtres+combles +Façades | eRen, sc1 | 33.9 | C | 19.6 | 862 |

**Coûts eRen par mesure incluant les coûts de la mesure unitaire et les frais généraux ou prorata du coût de la mesure.*

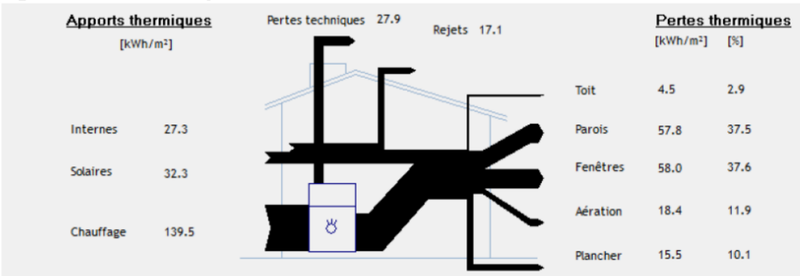
## Sheet for eREN No5 building typology

### eRen 5 – Bois Chapelle 57 (BC57)

**Modification par rapport à eRen :**
i. Méthode de calculs
ii. Station météorologique
iii. Adaptations mineures du bilan thermique existant

| | |
|---|---|
| Méthode de calculs | SIA 380/1 :2016 |
| Station météorologique | Genève - Cointrin |
| Année de construction | 1970 |
| SRE [m²] | 2 811 |
| Facteur de forme [-] | 0.796 |
| Besoin de chaleur limite[kWh/m²] | 34.6 |
| Coûts actualisé oct.2024 | eRen adapté IDC (base 100, oct.2015) |

**Diagramme de Sankey – Etat existant**




| Scénario de rénovation | Description | QH [kWh/m²] | Classe env. th | Puissance [W/m²] | Coûts unitaire* [CHF/m² SRE] |
|---|---|---|---|---|---|
| Etat existant | - | 111.6 | G | 49,6 | - |
| i. Plancher RDC | | 98,1 | G | 45,1 | 54.- |
| ii. Fenêtres | | 80,9 | G | 36,4 | 226.- |
| iii. Façades | Étages + attique+ caisson de store | 69,1 | F | 35,3 | 465.- |
| iv. Plancher + Fenêtres | | 68,5 | F | 32,3 | 280.- |
| v. Façades + Fenêtres | | 39,1 | D | 21,4 | 691.- |
| vi. Façade + Plancher | Sc 1 eRen | 57,3 | E | 31,2 | 518.- |
| vii. Façade + Plancher + Fenêtres | Sc2 eRen | 27,6 | C | 17,4 | 745.- |

**Coûts eRen par mesure incluant les coûts de la mesure unitaire et les frais généraux au prorata du coût de la mesure.*

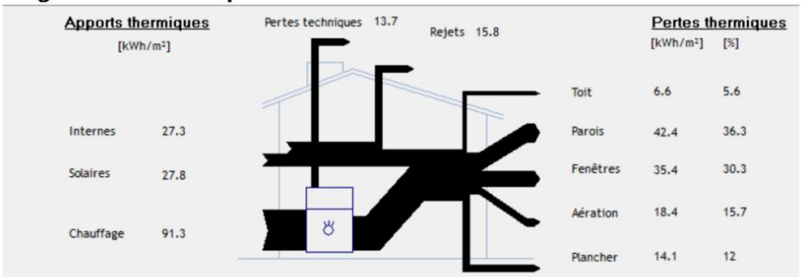
## Sheet for eREN No7 building typology

### eRen 7 – Fôret 20

**Modification par rapport à eRen :**
i. Méthode de calculs
ii. Station météorologique
iii. Adaptations mineures du bilan thermique existant

| | |
|---|---|
| Mode de calculs | SIA 380/1 :2016 |
| Station météorologique | Genève - Cointrin |
| Année de construction | 1975 |
| SRE [m²] | 5 065 |
| Facteur de forme [-] | 0.752 |
| Besoin de chaleur limite [kWh/m²] | 33.7 |
| Coûts actualisé oct.2024 | eRen adapté IDC (base 100, oct.2015) |

**Diagramme de Sankey – Etat existant**




| Scénario de rénovation | Description | QH [kWh/m²] | Classe env. th | Puissance [W/m²] | Coûts unitaire* [CHF/m² SRE] |
|---|---|---|---|---|---|
| Etat existant | - | 77.6 | G | 39 | |
| Fenêtres | Selon eRen + psi 0.04 | 55.7 | E | 29.6 | 186 |
| Plancher | Selon eRen | 66.9 | F | 35.2 | 35 |
| Toiture | Selon eRen | 72.7 | G | 37.3 | 81 |
| Stores+murs ss-sol | Selon eRen | 66.6 | F | 35.1 | 70 |
| Fen. + plancher | | 45.4 | E | 26 | 221 |
| Fen.+ plancher + Toiture | | 40.8 | D | 24.3 | 302 |
| Fen.+Plan.+Toit.+Stores+Mur Mss-sol | Sc.1 eRen | 30.4 | C | 20.5 | 372 |

****Coûts eRen par mesure incluant les coûts de la mesure unitaire et les frais généraux au prorata du coût de la mesure.***

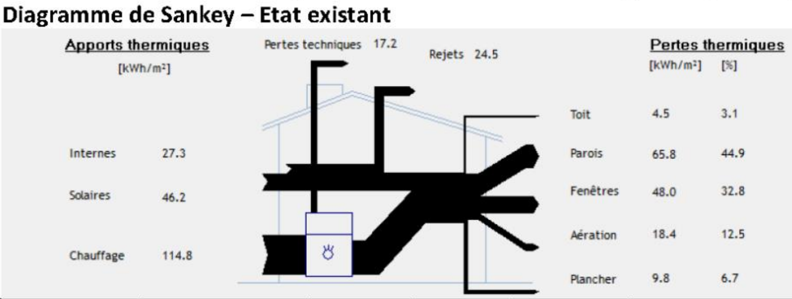
## Sheet for eREN No8 building typology

### eRen 8 – BC89

**Modification par rapport à eRen :**
i. Méthode de calculs
ii. Station météorologique
iii. Adaptations mineures du bilan thermique existant

| | |
|---|---|
| Mode de calculs | SIA 380/1 :2016 |
| Station météorologique | Genève - Cointrin |
| Année de construction | 1971 |
| SRE [m²] | 3 539 |
| Facteur de forme [-] | 0.656 |
| Besoin de chaleur limite [kWh/m²] | 31.7 |
| Coûts actualisé oct.2024 | eRen adapté IDC (base 100, oct.2015) |

**Diagramme de Sankey – Etat existant**




| Scénario de rénovation | Description | QH [kWh/m²] | Classe env. th | Puissance [W/m²] | Coûts unitaire* [CHF/m² SRE] |
|---|---|---|---|---|---|
| Etat origine | - | 97.6 | G | 47.2 | - |
| a. Fenêtres | Selon eRen avec psi 0.04 | 60.9 | F | 33.8 | 345 |
| b. Façades | Selon eRen | 49.8 | E | 30.5 | 494 |
| c. Fenêtres/ Attique/ Plancher | | 59.5 | F | 33.2 | 522 |
| d. Fenêtres/ Façades | | 24.8 | C | 19.6 | 839 |
| e. Fenêtres/ Façades/ Plancher/ Attique | eRen SC1 (=SC2 dans BLD) | 23.5 | C | 19.1 | 1016 |

**Coûts eRen par mesure incluant les coûts de la mesure unitaire et les frais généraux au prorata du coût de la mesure.*

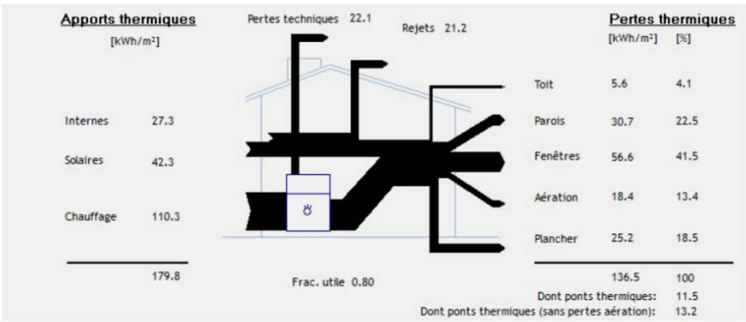
## Sheet for eREN No10 building typology

### eRen 10 – La Roseraie

**Modification par rapport à eRen :**
i. Méthode de calculs
ii. Station météorologique
iii. Adaptations mineures du bilan thermique existant

| | |
|---|---|
| Mode de calculs | SIA 380/1 :2016 |
| Station météorologique | Genève - Cointrin |
| Année de construction | 1988 |
| SRE [m²] | 5 215 |
| Facteur de forme [-] | 0.89 |
| Besoin de chaleur limite [kWh/m²] | 36.6 |
| Coûts actualisé oct.2024 | eRen adapté IDC (base 100, oct.2015) |

### Diagramme de Sankey – Etat existant




| Scénario de rénovation | Description | QH [kWh/m²] | Classe env. th | Puissance [W/m²] | Coûts unitaire* [CHF/m²SRE] |
|---|---|---|---|---|---|
| Etat existant | - | 88.2 | G | 44 | - |
| a. Plafond sous-sol + murs contre non-chauffé selon eRen | Plafond:<br>- EPS 20cm<br>- λ = 0.036 W/(mk)<br>Murs :<br>- EPS 10cm<br>- λ = 0.036 W/(mk) | 66.4 | F | 33.8 | 86 |
| b. Fenêtres façades selon eRen | - Uv : 0.6 W/(m²K)<br>- Uf : 1.1 W/(m²K)<br>- gp=0.45 [-]<br>- PSI: 0.04 W/mK | 62 | F | 31 | 287 |
| c. Fenêtres, plafond sous-sol et murs contre non chauffé | Cf. a et b | 37,2 | D | 22.5 | 373 |

**Coûts eRen par mesure incluant les coûts de la mesure unitaire et les frais généraux au prorata du coût de la mesure.*

## 10.2 Installed heat emitters capacity and optimized heating curves

**Installer heat emitters capacity**

To determine the installed heat emitters capacity for each building typology presented in Chapter 3, the non-renovated building is simulated on an hourly basis in TRNSYS (RC model described in section 3.3) with an ideal space heating system which maintains the indoor temperature equal to the chosen setpoint temperature (e.g. 20°C), thereby obtaining the building space heating demand, accounting for the solar gains, equipment gains, heat losses, etc.

Using the energy signature of the building based on daily space heating values, we determine the SH load for an outdoor temperature of -10°C (Figure 23). The outdoor air temperature of -10°C corresponds to the design temperature globally used for the Swiss Plateau during the considered building construction period. As described in Equation (8), the installed heat emitters capacity $Q_{rad,design}$ is equal to that SH load ($Q_{SH,design}$), with a safety factor of 20% (hypothesis). This safety factor is used to account for the fact that calculations of the SH load are usually done for a zone without internal gains or solar gains, and might have also included some oversizing. Since the value of this factor will have an influence on the SH supply/return temperatures, a sensitivity analysis will be performed to evaluate the impact on the system.

$$Q_{rad,design} = Q_{SH,design} \cdot 120\% = Q_{SH}(T_{outdoor} = -10°C) \cdot 120\% \tag{8}$$

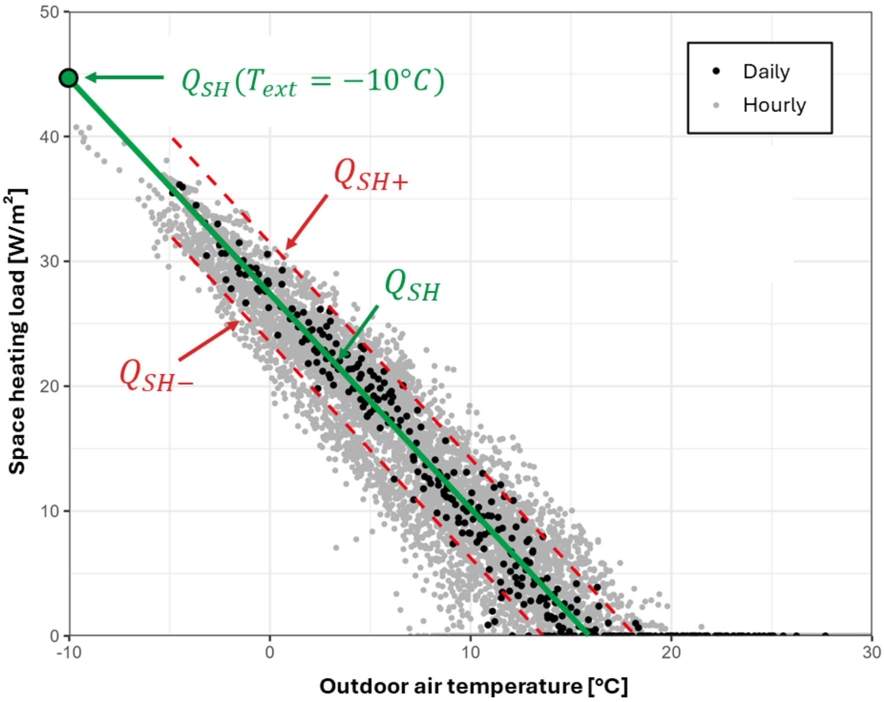



Figure 23: Building energy signature produced from hourly simulation of the non-renovated building with an ideal SH system and an indoor temperature setpoint of 20°C. Example of the TypoReno G3 building typology.

The heat emission capacity of the radiators depends on the type of radiators (cast-iron, aluminum,…) and the involved temperatures. It is defined for a specific set of supply/return/indoor temperatures. At design conditions, these temperatures are considered equal to 62/51/20°C (based on the temperatures typically observed in existing buildings [37]). Therefore, the installed heat emitters capacity at 62/51/20°C is the building space heating load for an outdoor temperature of -10°C ($Q_{rad,design}$), with a safety factor of 20%, as defined in Equation (8). The radiator constant K is then determined using Equation (9). This value is constant for a given heat emitter and does not depend on the operating conditions.

$$Q_{rad,design} = \mathrm{K} \cdot \Delta\mathrm{T}_{log}{}^{n} \Rightarrow K = \frac{Q_{rad,design}}{\Delta\mathrm{T}_{log}{}^{n}} \tag{9}$$

Where $n$ is the radiator exponent, equal to 1.3 as typical value for radiators

and $\Delta\mathrm{T}_{log} = \frac{T_{supply} - T_{return}}{\ln\left(\frac{T_{supply} - T_{indoor}}{T_{return} - T_{indoor}}\right)}$

For example, as illustrated in Figure 23, the SH load $Q_{SH,design}$ for an outdoor temperature of -10°C is 46 W/m² (113 kW) for building typology TypoReno G3. This leads to a heat emitters capacity $Q_{rad,design}$ of 56 W/m² (136 kW) at design conditions (62/51/20°C) and a radiator constant K of 1.28. When converted to EN442 standard conditions (75/65/20°C) using Equation (10), it corresponds to 84 W/m² (206 kW).

$$Q_{rad,EN442} = Q_{rad,design} \cdot \left(\frac{\Delta T_{log,EN442}}{\Delta T_{log,design}}\right)^{n} \tag{10}$$

The radiator thermal capacitance is set to 0.005 (kJ/K)/(kJ/h), as per manufacturers data reported in [54] for aluminum radiators.

### Optimized heating curves

To obtain the "low-flow" and "high-flow" heating curves (see section 4.2), we calculate, for each building typology and envelope retrofitting step, the lowest supply temperature ("high-flow") or return temperature (low-flow") required to meet the SH load across various outdoor temperatures. This process is illustrated in Figure 24 and involves the following steps:

- **Calculate the SH load $Q_{SH}^{+}$:** For a given outdoor temperature $T_{outdoor}$, determine the SH load using the building energy signature. To ensure the supply temperature is sufficient to meet the SH demand, we base the optimized temperature on the daily SH energy signature $Q_{SH}{}^{+}$, which covers 95% of the daily SH values (upper red dashed line on Figure 23).
- **Determine the average heat emitter temperature ($\Delta\mathrm{T}_{log}$):** Using Equation (11), calculate the average temperature difference across the heat emitters required to satisfy the SH load at a given outdoor temperature.

$$\Delta\mathrm{T}_{log}(T_{outdoor}) = \sqrt[n]{\frac{Q_{SH}^{+}(T_{outdoor})}{K}} \tag{11}$$

- **Compute the supply/return temperatures:** Determine the supply and return temperatures that correspond to the calculated $\Delta\mathrm{T}_{log}$, which either minimize the supply temperature ("high-flow") or minimize the return temperature ("low-flow"), while meeting a set of constraints. These constraints include the minimum/maximum admissible flow rate, the minimum temperature difference between the fluid and the indoor temperature, and the maximum supply temperature.

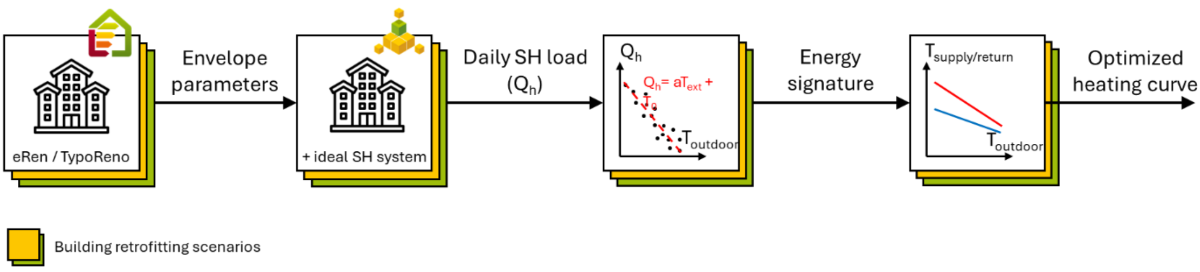



Figure 24: Process for the determination of optimized SH distribution temperatures (heating curves) for each building typology and envelope retrofitting scenario

## 10.3 Carbon emissions and renewable energy fraction of the Swiss electricity mix

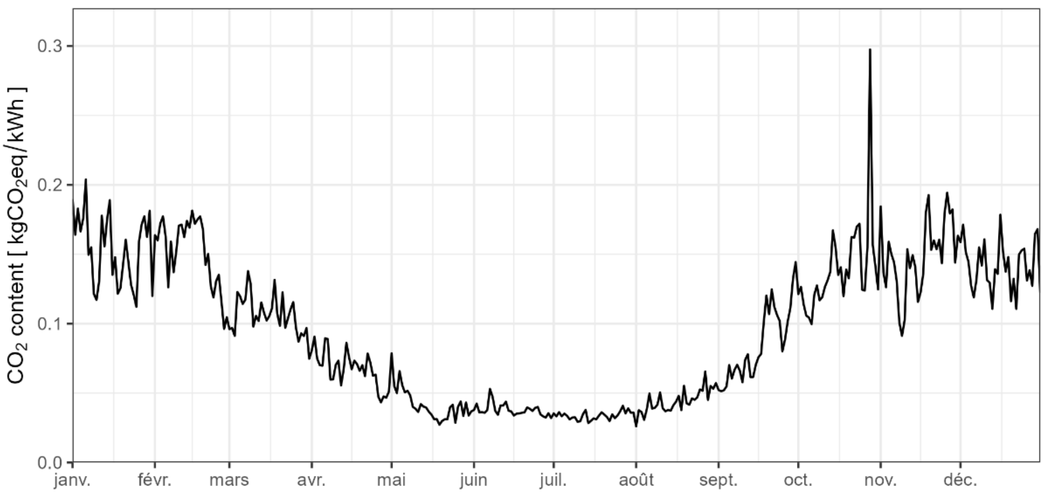



Figure 25: Daily $CO_{2eq}$ content of Swiss electricity consumer mix, 2017-2021 average. Source: Romano et al. [50]

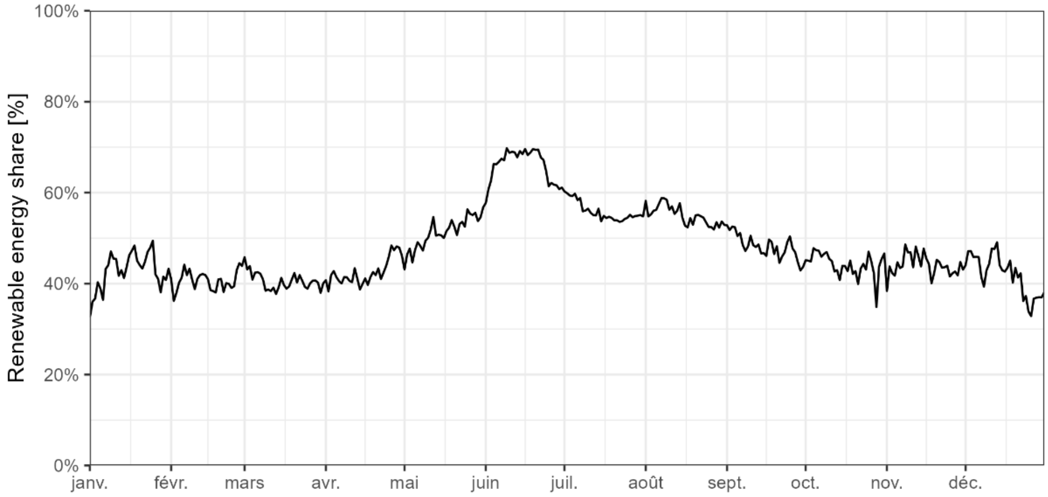



Figure 26: Daily renewable energy fraction of Swiss electricity consumer mix, 2017-2021 average. Source: Romano et al. [50]