D4.2 District Simulation platform description and validation through TRL 6 test

WP4

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Executive Summary

EDF R&D has been working within the WP4 on the modelling of the coupling of embedded heat production technologies in buildings with existing district heating network (DHN). Modelica is used for this work, so that the new models can be connected to models from MixSysPro, the Modelica library developed by EDF R&D for DHN model. It also facilitates the connection with the model from T4.1 which has been developed with Modelica.

Two DHN architectures have been studied to fill the need to exploit a low temperature heat produced by ENVISION technologies (45-50°C) with high temperature DHN (70-80°C) while allowing heat reinjection by the building which become both producer and consumer (prosumer: producer-consumer).

A sensitivity study on the impact of proportion of prosumer in the network has been carried out. Three scenarios have been set up with zero, one and eight ENVISION's building. It shows that each ENVISION's building increases the renewable energy (RE) rate of this network by 0.4% but also increases slightly the network energy losses.

Result	No ENVISION buildings	6% of ENVISION buildings	50% of ENVISION buildings
Total heating demand by substations on DHN [GWh/y]	21.647	21.080	16.934
Network Losses [GWh/y]	1.494	1.498	1.523
Network Losses rate [%]	6.9	7.1	9.0
Buildings energy injected [GWh/y]	0	0.117	0.940
ENR rate [%]	0	0.4	3.8

Please note the following important remarks:

- The layout of the heat network is not studied. Substations are in parallel after a network characterized by length and linear losses.
- This document only deals with the heating network part. Therefore, the behavior of the ENVISION buildings is an input data resulting from the work of other workpackages. The levers on the architecture only concern the heating network part, before the heat exchanger of the substation (the heat exchanger, localized in the substation, connects the secondary network to the primary network).

Table of Contents

List of Figures

Abbreviations and Acronyms

[DD] – Degree Day (a unit for measuring temperature difference integrated over time)

[DHN] – District Heating Network

[DHW] – Domestic Hot Water

[HTDH] – High Temperature District Heating

[LTDH] – Low Temperature District Heating

[RE] – Renewable Energy

[SST] – SubSTation of a DHN

1 Introduction

This document contains the description of the work conducted in the WP4 for the development of the numerical models for the coupling between building with ENVISION technologies and an existing DHN at district scale. One objective of the WP4 is to determine the energy performance at district level and to construct a control and management system at district level.

Different scenarios with the network connection (grid-coupled) and without the network connection (stand-alone) have to be modeling.

The model shall be able to estimate the impact of heat production of a building with the ENVISION technologies on the DHN (heat losses, power gain), taking into account:

- **local microclimate (**evolution of external temperature**,** seasonal variations in behavior)
- **ENVISION technologies implementation** (which technologies, on how many buildings)
- percentage of buildings using ENVISION technologies in the network

The models are to be used for support in demo site design, and for the assessment of the performance in various European climate and building / district configurations.

This document is structured in four chapters. The first chapter briefly presents the MixSysPro Library, used for DHN model at EDF R&D. The second chapter broach two network architectures, which fulfil the needs, and details the choice made. The third chapter concerns the development of models at district heating network scale. The fourth chapter details the hypothesis of the case study and the results of the coupling of district heating network with building with ENVISION solutions.

2 The Modelica library MixSysPro

2.1 MixSysPro – A Modelica library for district heating network modeling

The physical modelling of local energy systems is supported by the Modelica-based library « MixSysPro » [1] (LE BOURDIEC S. et al, 2018). The Modelica language enables an acausal modelling of complex systems. The latter can thus be broken down into elementary elements, whose physical dynamics are directly implemented with their behavioral equations. A complete system is derived from successive connections of such independent elements. The modular structure thereof enables a flexible usage of the library and an adaptability to tackle varied infrastructures and study cases.

A quasi-static modelling was chosen, as a good balance between reasonable accuracy of the results and computational time.

The way of modelling a DHN is the following: assembling sub stations (SST) (which correspond to an energy need at a certain temperature level) with energy sources (can be biomass, gas plant, heat pump, external sources, solar panel, etc.). The coupling of these two blocks need network and control system in order to form a district heating network. Weather also must be taken into account because of its potential impact on the demand, the losses and some productions sources such as heat pump.

Two subsets are available in the library for the modelling of local energy systems: one with the computation of power flows $\dot{Q}$, the other with the decomposition in mass flow rates $\dot{m}$, heat capacity c and temperature gap ΔT (1).

$$\dot{Q} = \dot{m} \cdot c \cdot \Delta T \tag{1}$$

Since the ENVISION technologies are based on low temperature production, the decomposition with mass flow rates, heat capacity and temperature modelling has been chosen to reflect the real issue to deal with temperature balance in order to reach a temperature set.

2.2 Content of the library MixSysPro

The library is composed of elementary modules organised according to the following structure:

- **Connectors:** Connectors represent the energy and/or mass flows exchanged between different modules
- **Resources:** The resources modules model the characteristics of the energy sources exogenous to the system (eg. electricity from the nation grid, biomass stock etc.)
- **Energy Demand:** The energy needs at the end-nodes of the network cover the needs for electricity, space heating, domestic hot water and specific energy needs
- **Energy Systems:** They cover energy production systems such as gas boilers, heat pumps, combined heat and power plants or centralized water tanks
- **Thermal Network:** Lumped models are used to model the district heating network and corresponding losses
- **Control blocks:** It includes the control strategies to operate the local energy systems
- **Toolbox:** Generic functions (eg. for database and time-series management)
- **Studies:** Complete study cases

2.3 Modelling with mass flow rates and temperature levels

In this modelling, the connectors use mass flow rate as flow variable and temperature as stream variable.

3.3.1. Demand

The example of the domestic hot water needs is detailed. The water volume consumption $\dot{V}_{water}$ is derived from the annual water consumption weighted with an annual (Figure below), monthly, and daily coefficients. (ADEME, 2016).

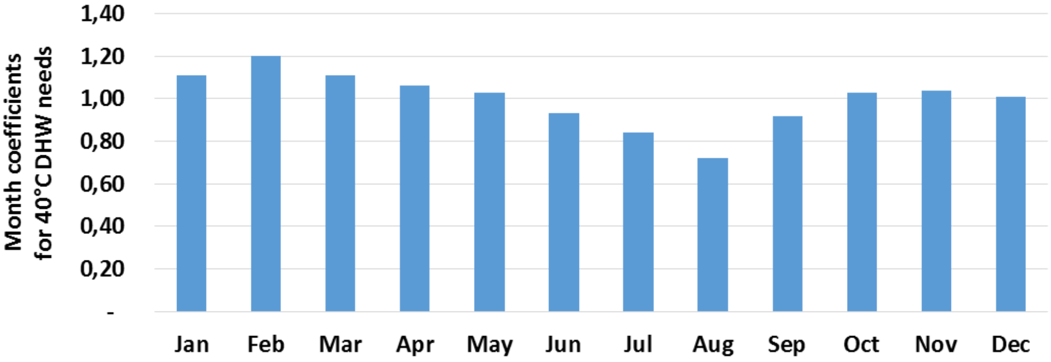


Figure 1: Example of month coefficients for the calculation of domestic hot water needs at 40°C from 81 standard residential buildings in the Yvelines, France[2] (ADEME, 2016)

The user specifies the temperature set point, tap water temperature and temperature after loop losses.

The Modelica module computes the mix temperature between the renewed and the recycled water from the mass and energy balance equations.

External modules impose the supply temperature from the primary side of the heat exchanger. It depends on the mix of the energy plants, which supply the district heating network, and on the network losses. The supply temperature from the secondary side is readjusted by considering the temperature pinch of the heat exchanger.

The corresponding power needs $\dot{Q}_{renewed}$ derived from (1) are computed with the water density ρ_{water}, heat capacity c_{water}, set point temperature $T_{set\ point}$ and the tap water temperature T_{tap} (2). Constant power needs are added to consider internal loop losses.

$$\dot{Q}_{renewed} = \dot{V}_{water} \cdot \rho_{water} \cdot c_{water} \cdot (T_{set\ point} - T_{tap}) \qquad (2)$$

3.3.2. Control strategy

The mass flow rate and the return temperature of the district heating network are imposed by the mix of end-users. The usage of the flow and stream variables in the connectors enable an automatic generation of mixing equations in the Modelica environment, considering the connections of the local energy system structure under study.

The energy plants are constrained with the maximum temperature they can provide and the maximum mass flow rate which can be heated. A by-pass is systematically modelled to channel the mass surplus. The information of the power left to be provided $\dot{Q}_{needed}$ and the mass flow rate available in the supplying pipe $\dot{m}_{available}$ is computed by the controller module.

A generic power plant, with a nominal installed power of $\dot{Q}_{nom}$ would be implemented following (3)-(6):

$$\dot{Q}_{max} = \max\left(0, \dot{m}_{available} \cdot c \cdot \left(T_{set\ point\ plant} - T_{ret}\right)\right) \tag{3}$$

$$\dot{Q}_{produced} = \max\left(0, min\left(\dot{Q}_{needed}, \dot{Q}_{nom}, \dot{Q}_{max}\right)\right) \tag{4}$$

$$\dot{Q}_{produced} = \dot{m}_{heated} \cdot c \cdot \left(T_{set\ point\ plant} - T_{ret}\right) \tag{5}$$

$$\dot{m}_{available} = \dot{m}_{heated} + \dot{m}_{by-pass} \tag{6}$$

3 DHN architecture

3.1 Introduction

This chapter is dedicated to the DHN's architecture able to fulfill the need of the transformation of consumer building to prosumers buildings. It only focus on the DHN part with main network part and substation part (heat exchanger); not on the secondary network part (network inside the building, after the heat exchanger).

Usually, the temperature range of most of the DHN is about 70-80°C [3](Bihen E. et al, 2018), [4](Frederiksen S et al, 2018). Except for the fourth generation DHN that have lower temperature range. However, this type of DHN is not yet very developed and mainly concerns new neighborhoods. Therefore, it will not be considered in this document since the ENVISION project focus on most common DHN with buildings renovation possibilities in order to integrate ENVISION innovative technologies.

The temperature range of ENVISION solutions are low temperature technologies (45-50°C) comparing to the temperature range of DHN (70-80°C). The architecture selected for the project should be able to couple the High Temperature District Heating (HTDH) with the low temperature building needs.

It also has to be able to absorb the excess heat at low temperature from the building.

Two architectures, which could meet the conditions, are presented.

3.2 Low Temperature District Heating

The behavior of building with ENVISION solution can be divided in three cases:

1- The building fulfills its own energy requirement without excess heat: there is no heat exchange between the building and the DHN.
2- The building produces less than its energy requirement: there is a lack of energy on the secondary side. The DHN has to supply the lack of energy respecting the low-temperature needs. Two possibilities exist to do that (the both can be combined):
    a. Low temperature on the primary network
    b. Low flow rate on the primary network
3- The building produces more energy than the energy requirement: there is an excess heat around 45-50°C on the secondary side. The excess of heat has to be absorbed by the network by re-heating the return of the primary.

To be able to couple HTDH with low temperature needs of a building with an existing DHN, the more common method is to create a Low Temperature District Heating (LTDH) loop [5] (Volkova A et al, 2020).

3.2.1 Mixing shunt

The first architecture presented in this chapter is a mixing shunt architecture. In this option, there are two pipes of the main network connected to the mixing station: the return pipe of the low-temperature network and the supply pipe of the primary network. Flows are mixed and connected to the supply of the low-temperature network. A pump is required to inject a certain amount of the return into the mixing station. There is a valve on the return of the LTDH loop which is directly linked with a temperature sensor in the mixing station. The temperature sensor controls the opening/closing of the valve in order to reach the setpoint temperature.

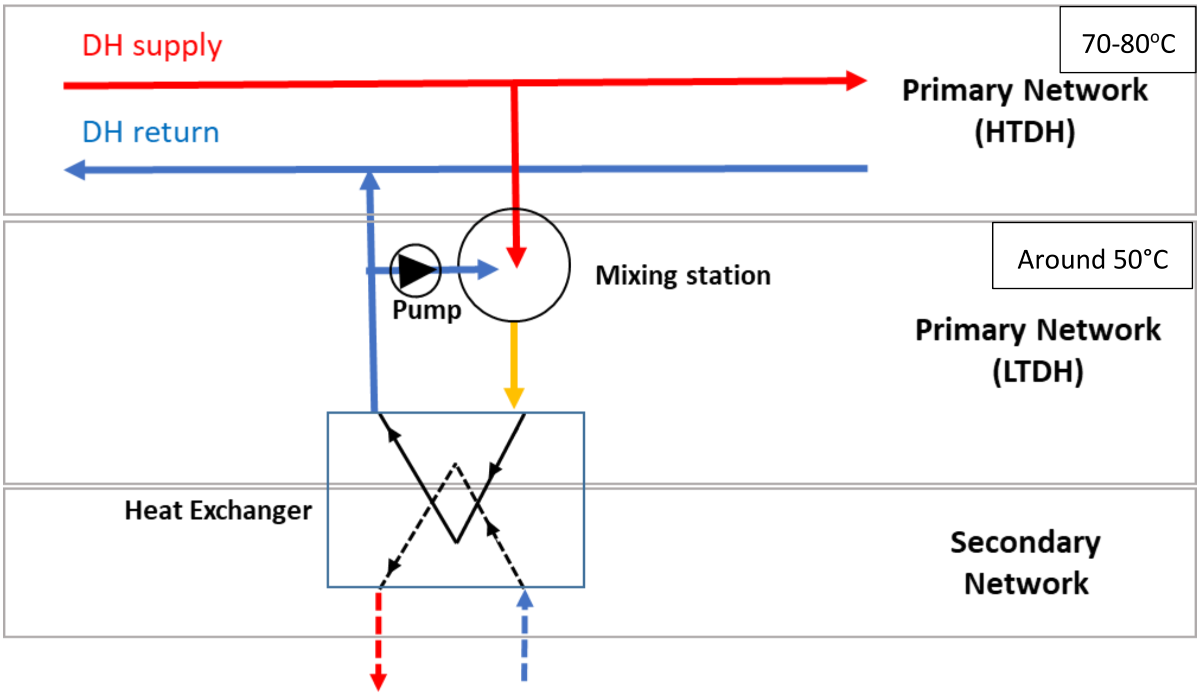


Figure 2: Diagram of the mixing shunt

3.2.2 3-pipes connection shunt

In this option, there are three pipes connecting the HTDH primary network to the LTDH. The temperature of the supply of the LTDH is reached by mixing the return of the primary network (other clients) with the supply of the primary network into the mixing station.

The return of the LTDH is sent to the return of the primary network.

It is possible to use up to 100% of the return pipe flow in the LTDH supply, or to mix it with the main supply to reach the setpoint temperature.

A boost pump is required after the mixing station since the return of the LTDH is at the same pressure than the return of the primary network.

There is a 3-way valve at the mixing station in order to control the amount of flow coming from the supply and from the return of the primary network to reach the setpoint temperature [6] (Kaarup Olsen P. et al, 2014)

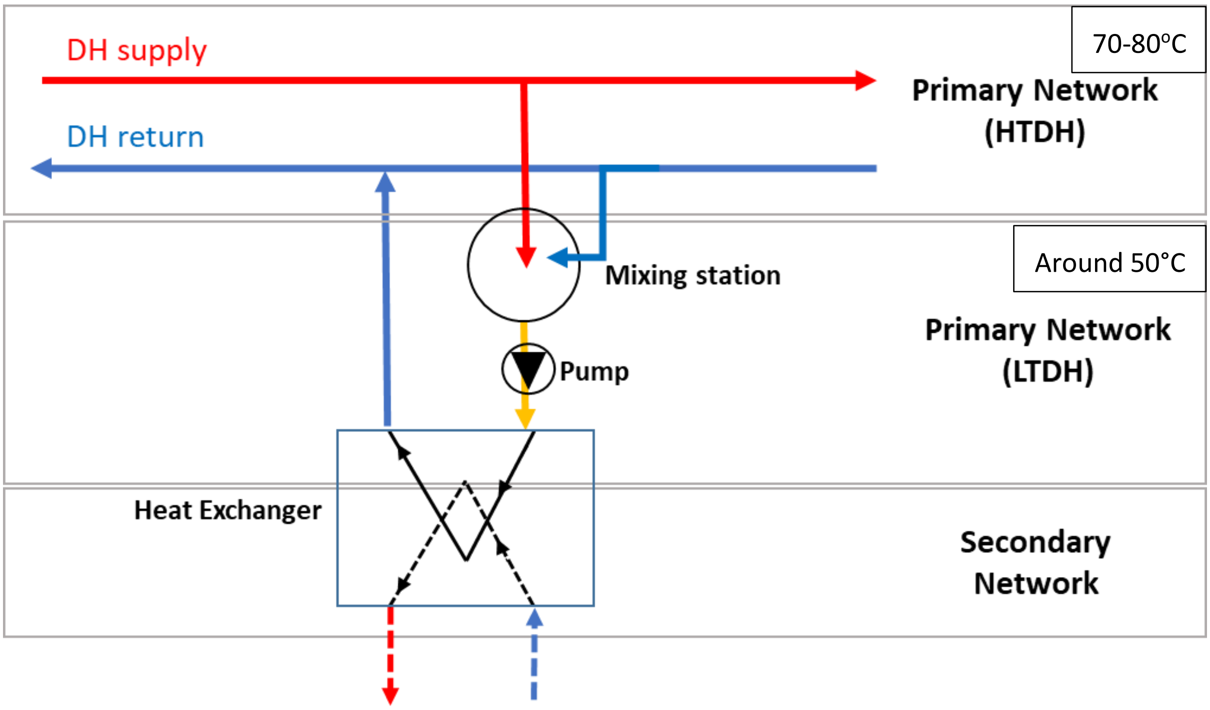


Figure 3: Diagram of 3-pipes connection shunt

3.2.3 Comparison of the two options – mixing shunt or 3-pipes connection shunt

In this part, we will challenge the two options described above to find the one that can reach ENVSION's specifications:

1- Need of low temperature supply from the network ("heating" mode)
2- Need to eject excess heat on the network ("cooling mode")

In both cases, the inlet of the heat exchanger is the result of a mix of the DH supply and a return flow: Heat Exchanger return for the mixing shunt architecture and DH return for the 3-pipes connection shunt architecture.

3.2.3.1 Heating mode

At first, for the low temperature heating mode, the both solutions need an additional pumping comparing with a classical HTDH network. The mixing solution requires less additional pumping than the 3-pipes connection shunt since there is a need to pump only for the part of the return's flow which has to be mixed into the mixing station. At the opposite, the 3-pipes option requires a need for the totality of the input flow with a higher pumping cost.

In both cases, the substation needs to be modified with an additional pipe. With the mixing solution, the pipe can be added in the substation (at the primary network side), from SST return to mixing station. On the contrary, 3-pipes option needs a direct connection on the return from other clients, often located outside the building. That means that an additional pipe between the main return outside the building and the mixing station at the primary has to be added. The location of the mixing station depends of the local constraints. Investment cost is higher in this case.

In both case, an investment in the mixing station is required.

To apply any mixing solution, the return flow rate of the LTDH loop should be high enough to enable the mixing. The 3-pipes option requires return flows from other consumers. Therefore, it cannot be implemented at the end of the network.

The specificity of the ENVISION project is that the network can be whether in “heating mode” at low temperature or in “cooling mode” with an excess heat in the building which has to be evacuated into the DHN.

3.2.3.2 Cooling mode

At certain periods of the year (like in summer for example), the ENVISION technologies will provide more heat than the requirement. This is because, in summer, there is more solar irradiation with fewer needs of DHW and space heating. Therefore, the excess heat will be injected into the secondary network.

That means that, during this period, the LTDH network will not work as a low temperature heat network but as a cooling network (the primary network has to get the excess of heat instead of feeding the secondary network with heat).

The designed network should be able to absorb this heat excess in its return pipe.

Mixing shunt:

The return of the pipe on the LTDH loop is directly mixed with the main supply in order to reach the setpoint temperature. In the “cooling” mode, the excess heat produced by the building will be injected in the return.

The direct consequence of it will be a higher temperature supply (since the return will be at higher temperature). But the higher the supply is, the less efficient the cooling will be. Moreover, too many excess heats to evacuate could lead to a need of a cooling device in the building due to too high temperature supply on the primary. Indeed, if the heat pump produces too much heat, the flow at the secondary network return will be at high temperature. However, this flow is supposed to be mixed with main supply in order to reach the setpoint temperature of the secondary network.

For example, let us consider a temperature return of the substation (after the heat exchanger) at 70°C and a setpoint temperature expected at 50°C.

With this architecture, the inlet of heat exchanger is the result of a mix of main supply and substation return. Since the DH supply is around 70-80°C, it will be impossible to reach the setpoint temperature of 50°C by mixing two flows at 70°C. That means that a cooling utility will be required in the house to counterbalance this excess of heat.

3-pipes connection shunt:

In this configuration, the return of the LTDH loop is mixed with the return of the primary network before the LTDH loop and is injected after the LTDH loop. The temperature of the LTDH supply is the result of a mixing between the primary return before the loop and the primary supply. Therefore, the temperature of the supply is not affected by the temperature of the LTDH return and can remain low despite the injection of excess heat on the return.

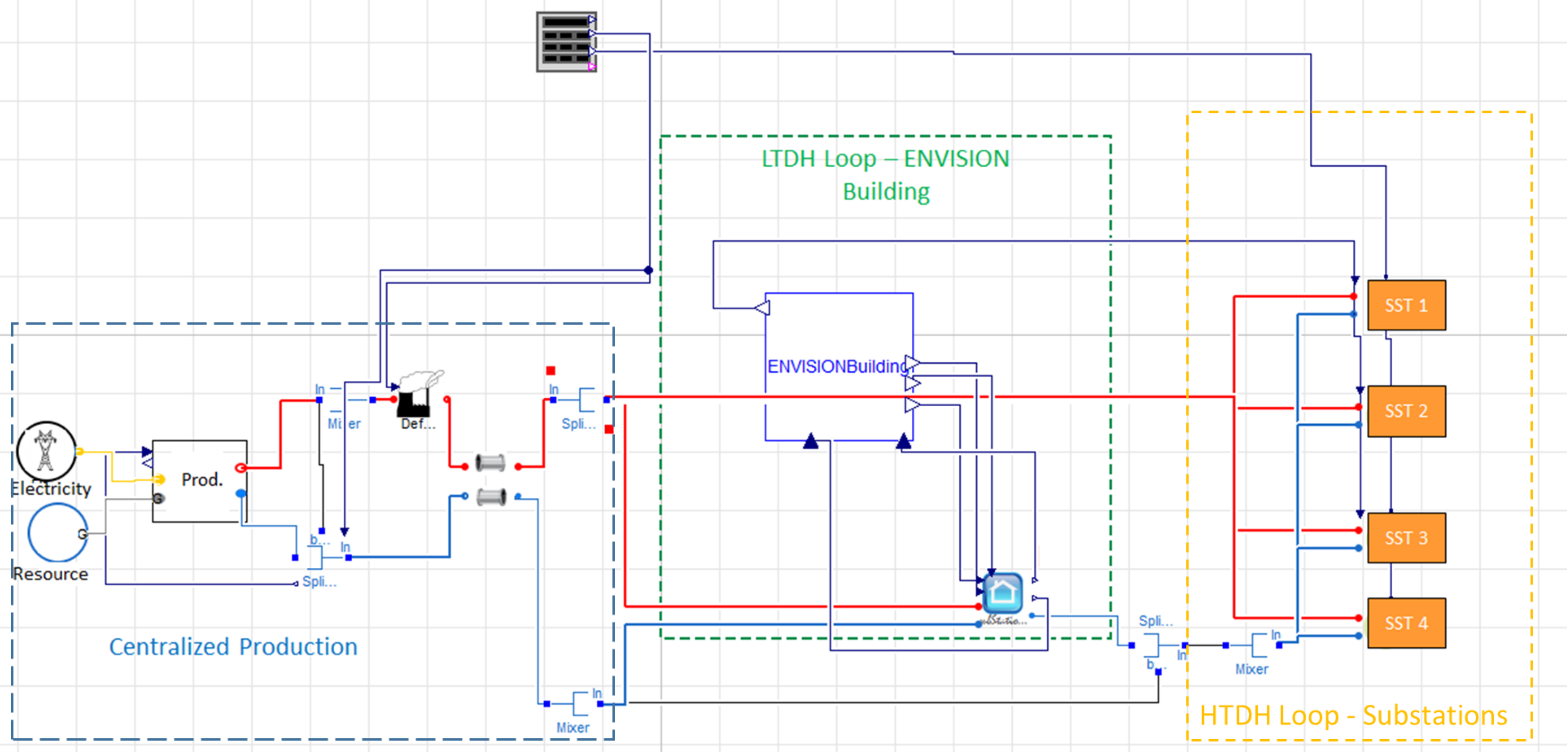
This solution meets the needs of the building: a network able to supply flow at low temperature and able to work as a “cooling loop” by absorbing the building’s excess heat.

Comparing the two options, the 3-pipes connection shunt will be considered for the modelling work and in the rest of this document since it meets every constraint of the ENVISION technologies.

4 The Modelica model

The chapter explains the way of modeling the coupling between DHN and buildings including some ENVISION building. The goal of this chapter is to present the global idea of the model and not to describe every equations of every blocks.

4.1 Global overview



The District heating Network is modelled by a supply (red pipe) and a return (blue pipe) of flows described by a temperature and a mass flow rate. It includes heat losses and impact of the local weather with the setting of external temperature through a year.

The model is divided in three parts:

- The Centralized Production (Blue area on the figure above)
- The High Temperature District Heating Loop which includes the more “common” substations (Orange area on the figure above)
- The Low Temperature District Heating Loop which includes ENVISION buildings (Green area on the figure above)

4.1.1 Centralized Heat Production

The centralized heat production contains every heating power plants of the district heating network. One or several heat plants (gas plant, biomass plant, cogeneration, etc.) produce heat to meet the client’s needs and consume electricity or primary resource (such as gas, biomass, fuel …).

In addition to the specific characteristics of each type of heating plant, many general settings such as availability, efficiency, power consumption or technical minimum influence the heat plants behaviour.

The centralized production produces the amount of heat needed - as long as it remains in the operating range of the heat plants - to meet the both conditions:

- Power needed by client
- Temperature needed by client

To fill these two requirements and depending of the plant characteristics, part of the mass flow rate can be sent through a bypass to be mixed with the heating plant output.

4.1.2 The High Temperature District Heating Loop

The block “SST” corresponds to the substation (there is 4 substations in this model). This part represents the substations (the client) which has a need in space heating and/or in DHW. These substations only consume heat and do not produce it. The secondary network is not modelled here. Only the needs of the secondary are modelled.

The flow coming from the centralized production has to supply every client. A splitter separates this primary supply pipe in four parallel sub-pipes in order to supply every substation at the specific flow-rate corresponding to their needs.

After the splitting, the flow goes in the substation at a certain temperature and come back through the return pipe at a lower temperature (the temperature delta corresponds to the power consumed by the client).

The return flows of every substations are mixed to the main return pipe.

Note: In a “classical” DHN with only a HTDH, the return comes back directly to the production part.

4.1.3 Low Temperature Heating Loop

In this model, one or several buildings embed ENVISION technologies. They are not classical consumers but are prosumers (producer-consumer) [7] (Brange L., et al, 2015). The temperature range appropriate to meet their needs is a low temperature heating network.

In the model, the ENVISION substation supply is linked both to the primary supply and to the primary return. The ENVISION substation return flow is sent to the primary return.

The power and temperature needs are provided by the "ENVISION Building" Block (models of this part are presented in the WP4.1 of ENVISION Project) and sent to a substation.

There are two cases:

1- The power need is positive - it means that the solution "ENVISION technologies + HP" produces not enough heat to fill 100% of the building's heating needs. The DHN has to supply additional heat to the building.
2- The power need is negative - it means that the solution "ENVISION technologies + HP" produces more heat that the building's requirement. The DHN has to absorb this excess of heat.

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The model is managed in flow rate to meet the power needs.

In the first case, the flow rate comes from the primary supply at a temperature above the building return. There is no flow coming from the primary return to the ENVISION building. The behaviour is the same that the classical case presented in the previous section.

In the second case, the flow rate comes from the primary return at a temperature under the building return. The primary return absorbs heat from the ENVISION building and flow out at a higher temperature.

5 Case Study and modeling results

5.1 Description

The network studied in the paper [1] (Le Bourdiec et al, 2016) inspires this use case. A gas boiler produces hot water for households, a university and a hospital. The network is 3.5 km long with losses of 0.48 W/(m.K). The unit of heating needs is kWh/DD (Degree Days). Degree Days are the difference between the non-heating temperature (usually 18°C) and the daily average temperature. Only positive values are considered. The university count nearly 1000 students with a heating demand of 300 kWh/DD (620 MWh/year) and the hospital count nearly 500 beds with a heating demand estimated at 1750 kWh/DD (6,02 GWh/year).

We assumed that households have a medium energy performance with a consumption of 0.1 kWh/m²/DD according to a study on energy performance certification in Lithuanian building sector [9] (Norvaisiene et al, 2014). The consumption of an 80 m² household (average surface for ENVISION's households) is then 8 kWh/DD. In this use case, 384 households of 80 m² are connected to the network with a total heating demand of 3072 kWh/DD (263 kWh/m²/year).

Domestic hot water consumption is aggregated and estimated to 45 000 m3/year for all network.

The supply temperature of the heat network follows a heat curve characterized by the points 90°C at an external temperature of -7°C and 70°C at 15°C. Another heat curve calculates the return temperature of all consumers excepted ENVISION's buildings.

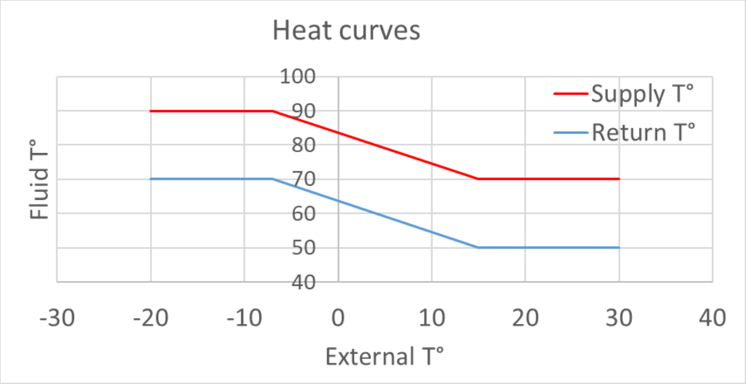

Figure 4: Network and consumers heat curves

Three simulations have been made to calculate the impact of ENVISION's renovations on district heating network. The first one is the initial case without any ENVISION's renovations, the second includes one renovated building (6% of connected households), and the third one includes eight renovated buildings (50% of connected households). To reduce calculation time of the last scenario, we calculated with only one building and the exchanged power at the substation was multiply by eight.

5.2 Results

ENVISION's renovations reduce the power demand all over the year. Heating demand is reduced thanks to better insulation and injected power reduce summer consumption (Figure 5). Maximal power is reduced by 25% in the case of the renovation of half of households. This could allow the network operator to connect new clients without add heat plant.

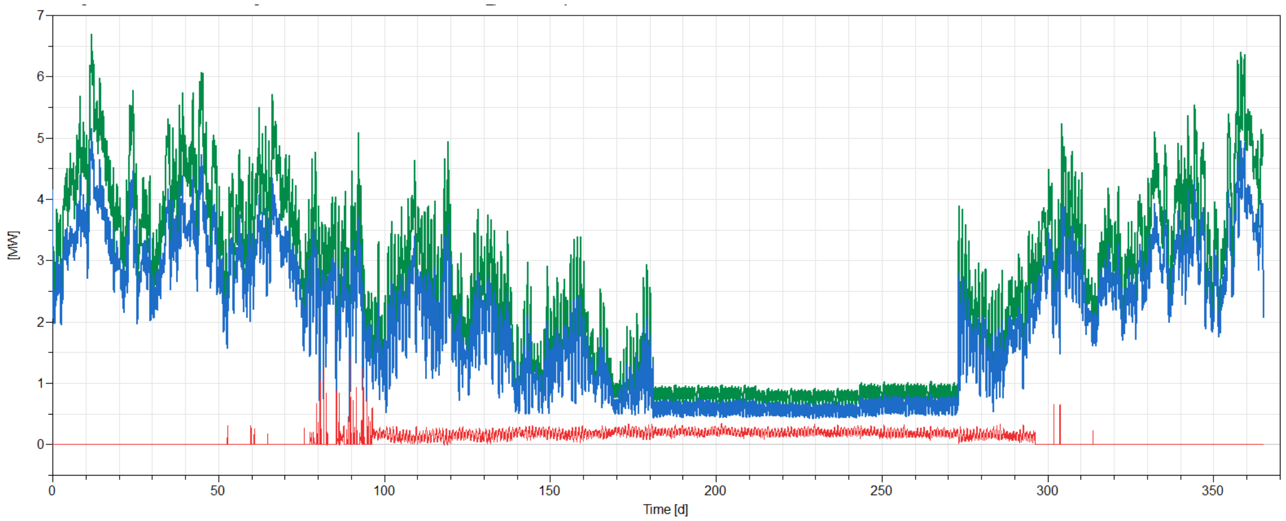

Figure 5: Evolution of gas plant power without renovation (green), with eight renovated buildings (blue) and their power injection (red).

The main indicator is the renewable energy part of the heat network. Heat pumps produce the energy injected by renovated buildings in the heating network. We calculate the renewable energy by subtracting electrical energy from thermal energy of the heat pumps (7).

$$E_{ENR} = E_{th\ condenser} - E_{elec\ compressor} \tag{7}$$

The performance of the heat pump is given by the coefficient of performance (COP) (8)

$$COP = E_{th\ condenser} / E_{elec\ compressor} \tag{8}$$

We can define the ratio of renewable energy in the thermal energy injected to the network by buildings (9)

$$E_{ENR} = E_{injected\ buildings} * \left(1 - \frac{1}{COP}\right) \tag{9}$$

We get the renewable energy rate of the network by dividing the renewable energy by thermal energy injected to the network (gas plant and buildings) (10)

$$Rate_{ENR} = E_{ENR} / (E_{produced\ boiler} + E_{injected\ buildings}) \tag{10}$$

The following table synthesis simulations results. It contains the energy produced by centralized heat source, the energy losses in the pipes of the primary network and the thermal energy injected by ENVISION's buildings.

	0 building	1 building	8 buildings
Households proportion [%]	0	6	50
Gas plant energy produced [GWh/y]	21,647	21,080	16,934
Losses [GWh/y]	1,494	1,498	1,523
Losses rate [%]	6,9	7,1	9,0
Buildings energy injected [GWh/y]	0	0,117	0,940
RE rate [%]	0	0,40	3,8
Maximal gas plant power [MW]	6,69	6,50	5,15

The energy produced by gas plant decrease significantly with the number of renovation due to better insulation, auto consumption of energy produced by heat pumps and injection of the excess energy.

We can see that network heat losses increase with the number of renovated buildings connected. This is a consequence of a higher return temperature when excess power is injected in summer. The increase represents around 3% of the injected power (around 3.4% for the one building simulation and around 3% for the 8 buildings simulation).

Most of the time, the network operator has an RE rate target. It is determined by the city or by financial incentives. Each ENVISION's buildings increase the RE rate of this network by 0.4%. This could help the network operator to reach his objective.

6 References

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