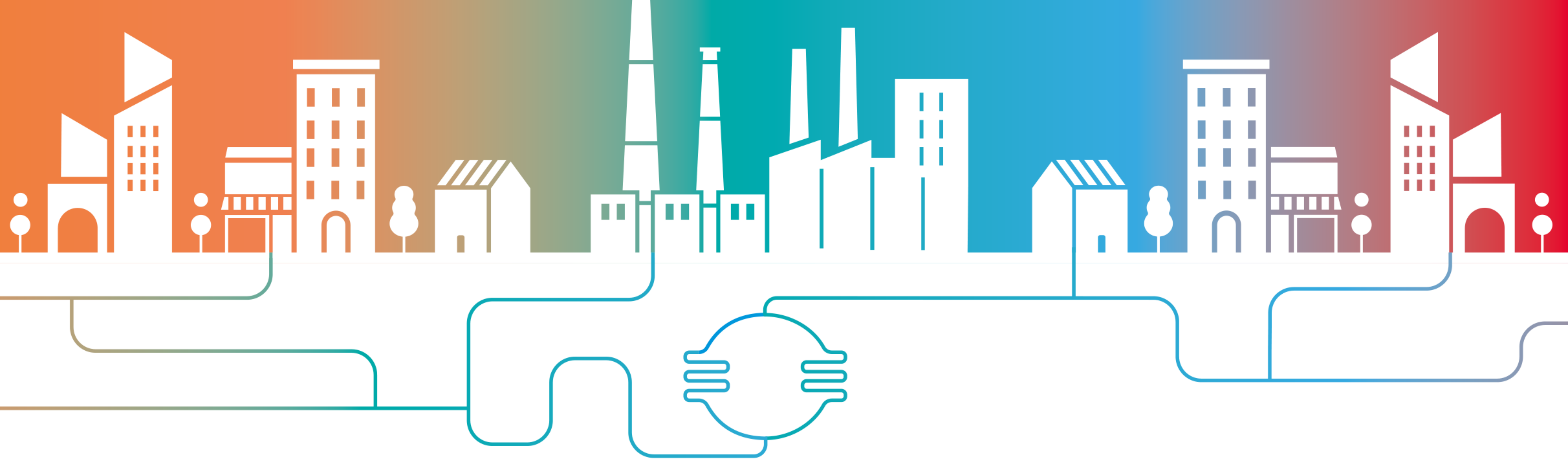


Educational kit – Action E.2

Daniele Anania, Marco Cozzini – EURAC Research

June 2024

LIFE 4 HEAT RECOVERY

Table of content

INTRODUCTION

Introduction

District Heating (DH) is a technology to transfer heat through a pipe network from one or more production points to several final users. Its fundamental idea is "to use local fuel or heat sources that would otherwise be wasted to satisfy local customer heat demands". (*Source: S. Frederiksen and S. Werner, District Heating and Cooling, First Edition, 2013*).

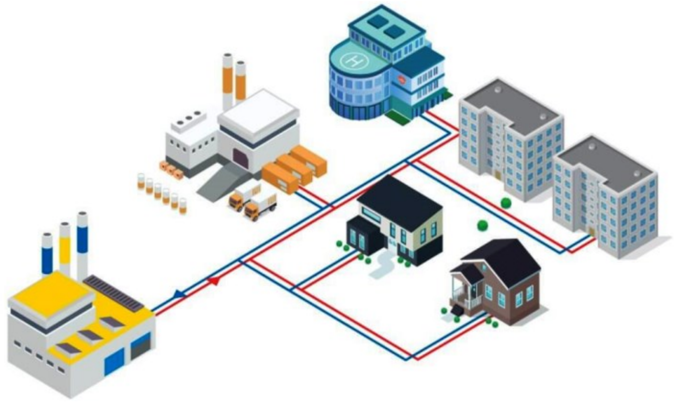
Why district heating?

District heating systems' main advantages:

- allow flexibility in the choice of the heat sources;
- permit more cost-effective operation and independence of a sole heat source;
- enable opportunities to use local energy resources and to reduce fossil fuel consumption;
- the centralized heat generation benefits from using large units that have higher energy efficiency, are equipped with more advanced control and can benefit from economy of scale.

When does district heating make sense?

District heating systems are generally considered a valid solution to satisfy the heat demand of the users in areas with a high-demand density. Indeed, having a high linear demand density (i.e., heat demand per unit length of the network) allow to keep low distribution costs, mainly represented by thermal losses, pressure drops along the pipes, and investment cost of the network.



Source: solarthermalworld.org

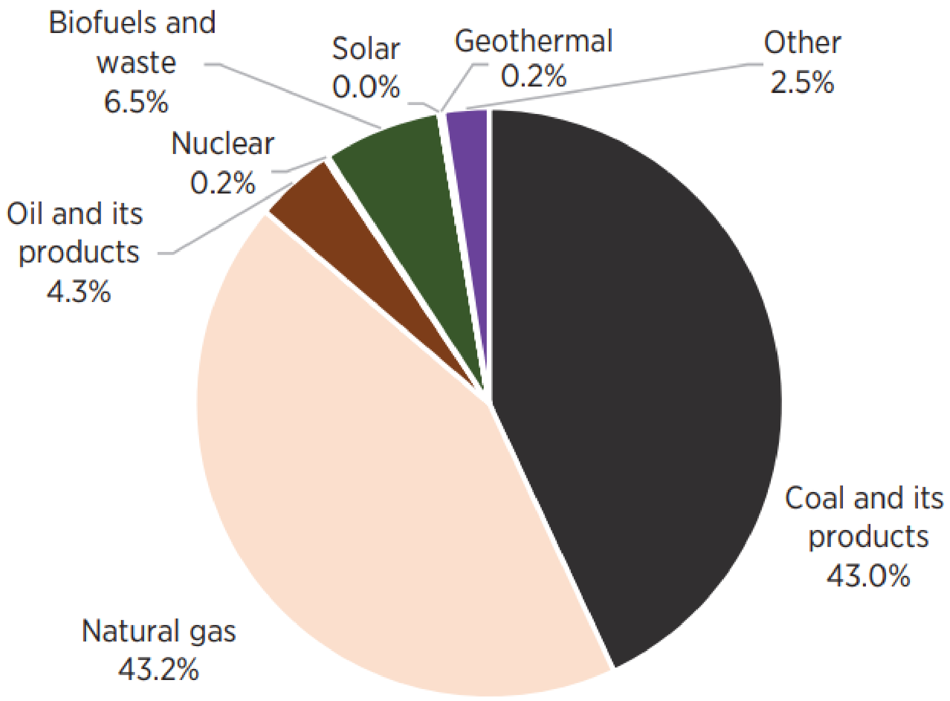
Facts

Today, in most countries, renewables account for only a minor proportion of the energy used in district heating systems!!!

The mix of fossil fuels is covered predominantly by coal (43%), especially in China, by natural gas (43.2%), in particular in Russia, and by oil (4.3%). **Renewables represented less than 8%** of global district heating supplies.

Europe currently leads renewables integration in district heating, with about 25% of its district heat supplies produced from renewable sources. Particularly high rates are observed in countries such as Sweden, Denmark, Austria, Estonia, Lithuania, Latvia, and Iceland where more than 50% of district heat is fuelled by renewables.

Breakdown of fuel use in District Heating and Cooling systems worldwide, 2014



Source: International Energy Agency (IEA), 2016.

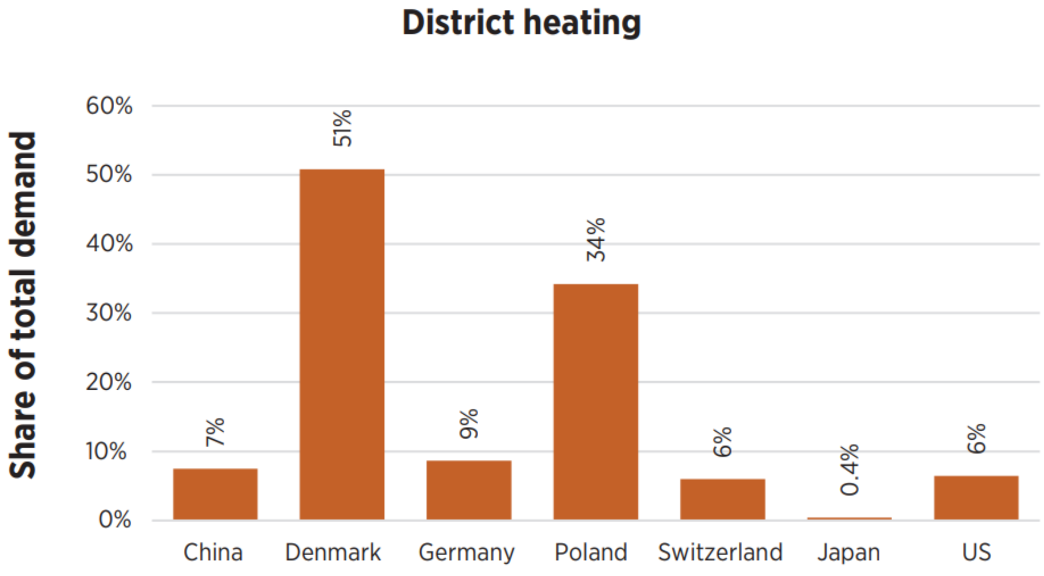
Facts

Parameters illustrating volumes of heat supply from district heating networks in selected countries

	Unit	China	Denmark	Germany	Poland	Switzerland	Japan	United States
Heat sold	*PJ*	**3182**	**107**	**399**	**344**	**18.3**	**9.0**	**455**
Installed DH capacity	*GW*	**462.6**	**30.0**	**49.8**	**56.5**	**2.5**	**4.2**	**89.6**
Network length	10^3 *km*	**187.2**	**29**	**20.3**	**16.1**	**1.4**	**0.7 (*)**	**3.3**
Number of networks	-	**/**	**394**	**1342**	**317**	**153**	**136 (*)**	**5800 (*)**

Sources:
China: National Bureau of Statistics of China (2016), Odgaard (2015); Denmark: Danish Energy Agency (2014), Dansk Fjernvarme (2014); Germany: BMWi (2015), AGFW (2015); Poland: IRENA, Central Statistical Office of Poland (2014); Switzerland: Bundesamt für Energie (2016); Japan: Kainou (2014), JHSBA (2016); US: IRENA, Euroheat & Power (2013), Cooper et al. (2012); multiple countries: Euroheat & Power (2015)

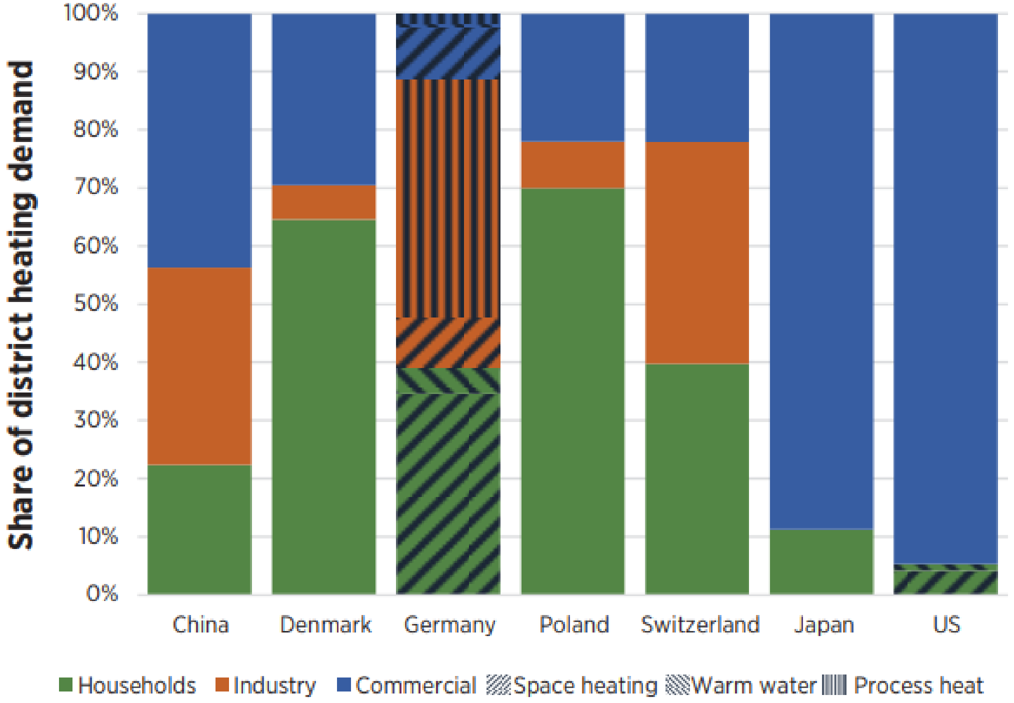
(*) district heating and district cooling together

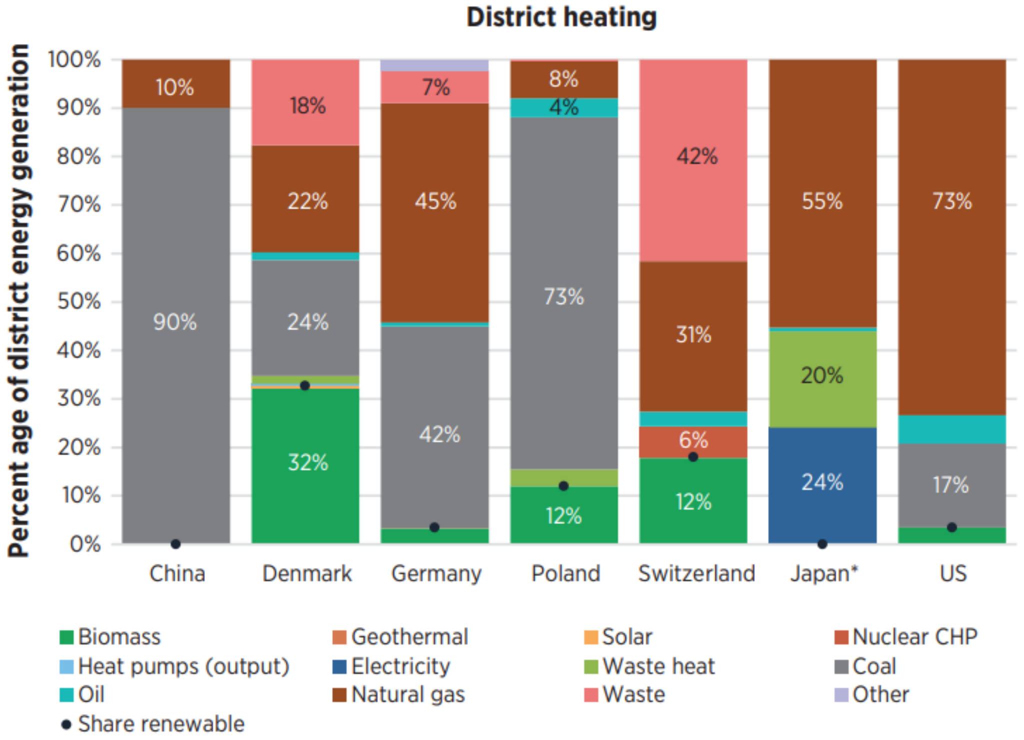


Source: Renewable energy in district heating and cooling – A sector roadmap for remap. IRENA (International Renewable Energy Agency), March 2017.

The last statistical survey by Euroheat&Power reports that about 6'000 district heating networks were in operation in Europe supplying **about 13%** of the total heat demand in 2017.
As reported by the IEA, district heating systems cover **only 8%** of the global final heat consumption.

Facts





Source: Renewable energy in district heating and cooling – A sector roadmap for remap. IRENA (International Renewable Energy Agency), March 2017.

Evolution of district heating and cooling

LIFE 4 HEAT RECOVERY

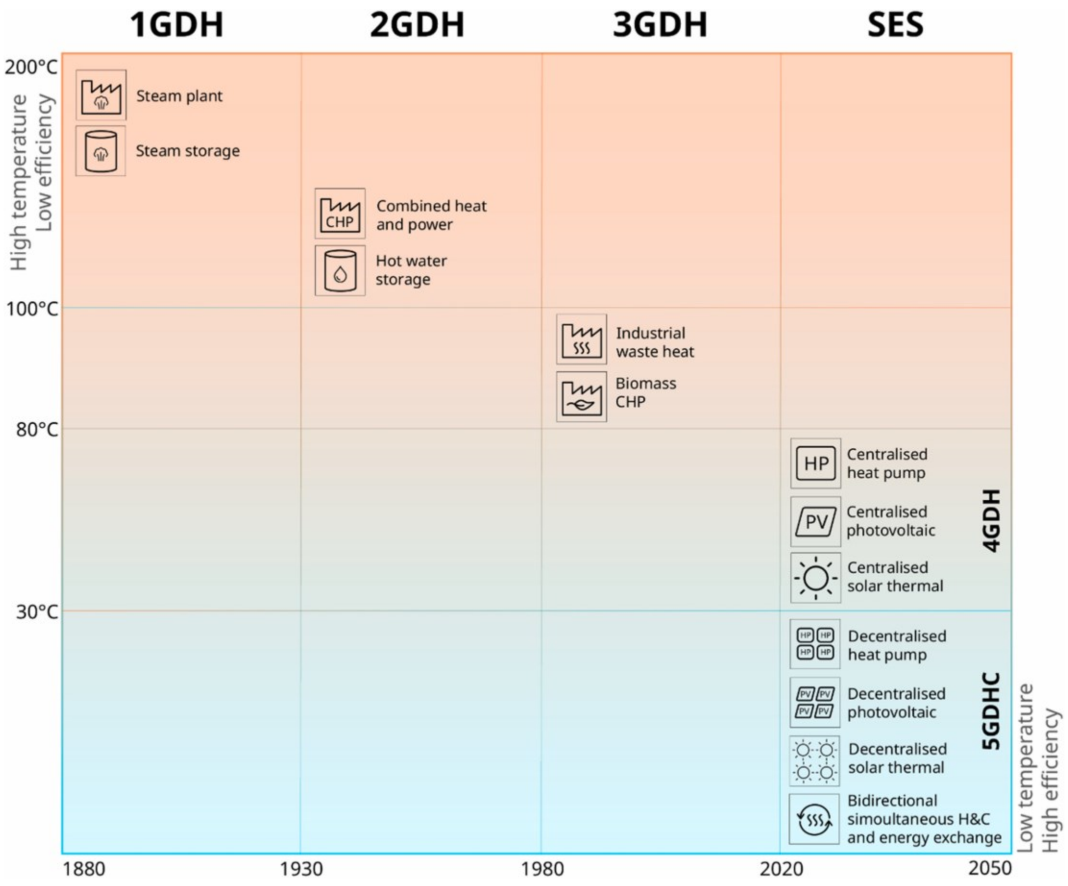
A **traditional district heating** (the first three generations of district heating) is characterized by high supply temperatures, **above 80 °C**.

The trend over the year is **to lower the distribution temperature** of the network allowing:

- the reduction of thermal losses;
- greater opportunities at incorporating low-temperature renewable energy sources and low-grade waste heat;
- the increase of the efficiency of heat production plants.

But there are also some weaknesses and threats:

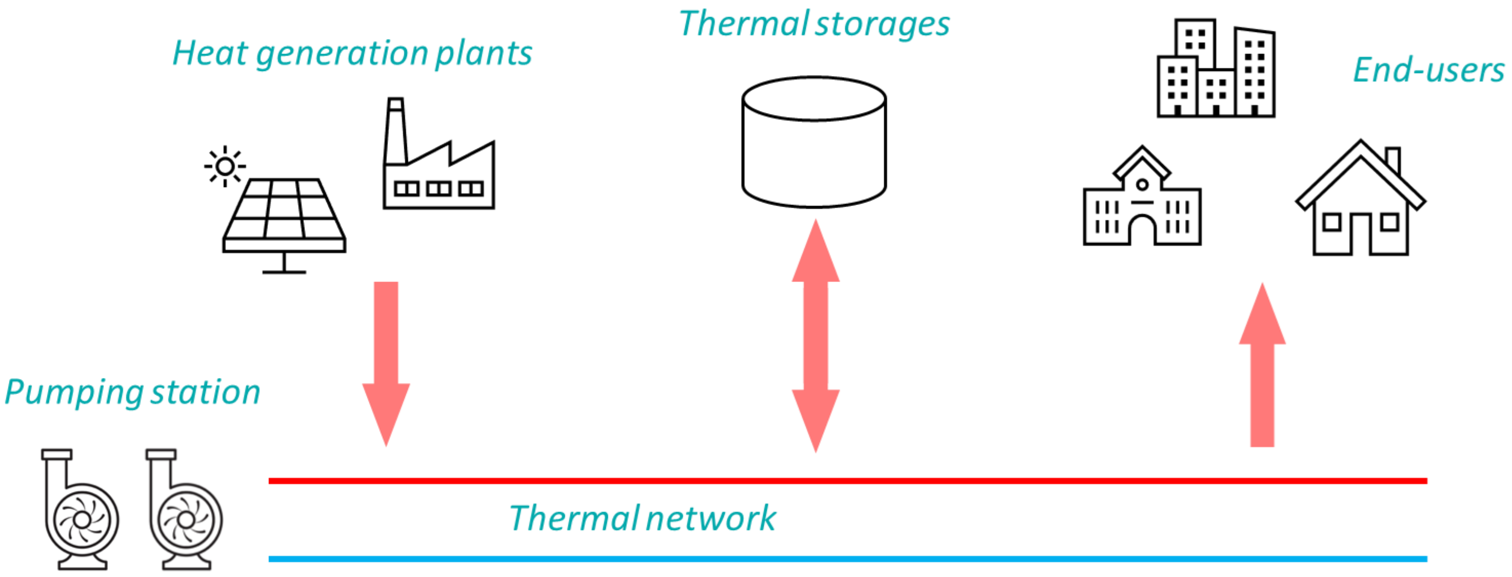
- the substations in the fifth-generation are more expensive than those in previous generations;
- larger pipeline diameter and storage thermal capacity are required due to the low temperature difference between supply and return pipes;
- high pumping costs per unit of energy due to small operative temperature difference and higher fluid viscosity;
- installation is invasive both for the pipelines and user substations;
- the approach in design and sizing adopted in traditional DH systems needs to be reviewed.



Source: K. Gjoka, B. Rismanchi, and R. H. Crawford, "Fifth-generation district heating and cooling systems: A review of recent advancements and implementation barriers".

STATE OF THE ART

District heating: overview of the main components



Heat generation plants: they supply heat to the network.

Network: it consists of underground pipes which transport the thermal energy from the heat sources to the end users.

Thermal storages: they consists of a heat reservoir that is cyclically charged and discharged during system operation.

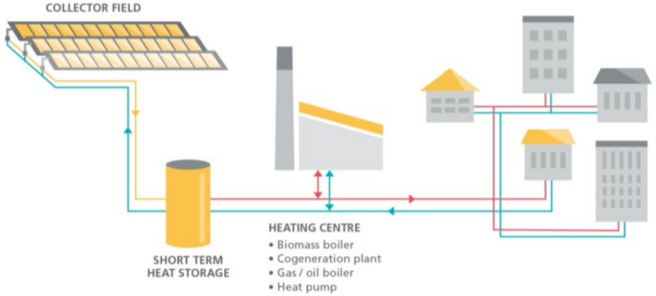
Pumping station: it ensures the circulation of the heat carrier fluid within the network.

End-users: they are the customers of the systems, extracting heat from the network. The interface between the end-user and the network is represented by the **substation**.

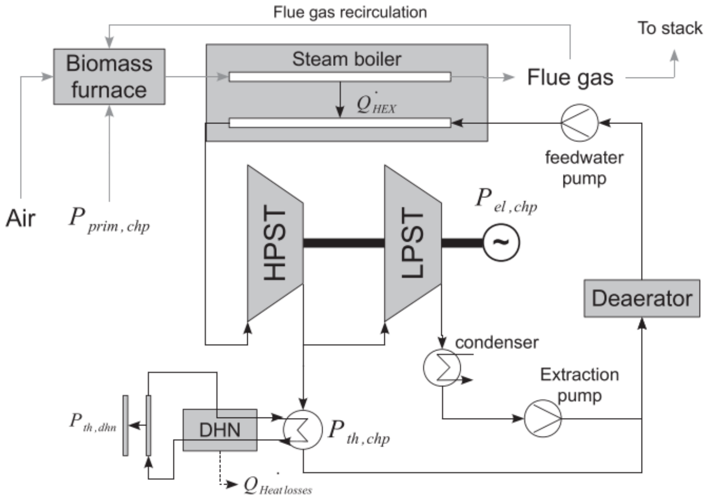
State of the art – Heat sources and heat carrier fluid

System	Heat sources	Heat carrier fluid
Traditional DH • 1st generation • 2nd generation • 3rd generation	• Gas boilers • CHP plants • Waste-To-Energy systems • Waste heat from industrial plants • Biomass boilers • Solar collectors	1st generation: steam 2nd and 3rd generation: pressurized water
New generation DH • 4th generation • 5th generation DHC	In addition to the previous: • Centralized heat pump • Geothermal resources • Low-temperature waste heat recovery (e.g., from data center, supermarkets…)	4th generation: water 5th generation DHC: water or water-glycol mixture

Copenhagen's Copenhill waste-to-energy plant
Designed by Bjarke Ingels Group
source: www.archpaper.com



Solar district heating
source: www.solar-district-heating.eu



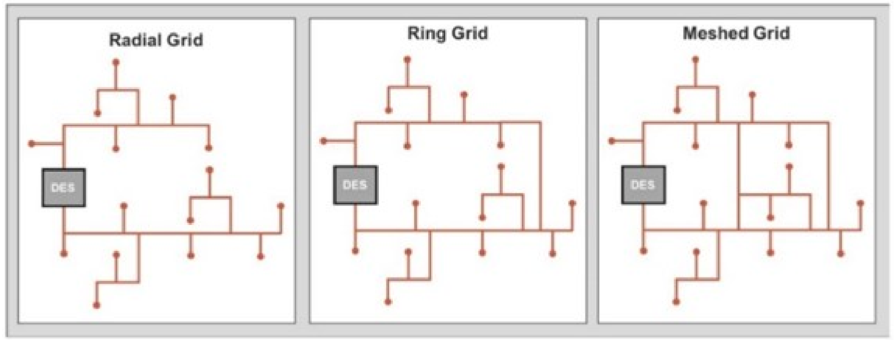
Schematic of CHP plant
source: Sartor K. et al - Simulation and optimization of a CHP biomass plant and district heating network

State of the art - Network

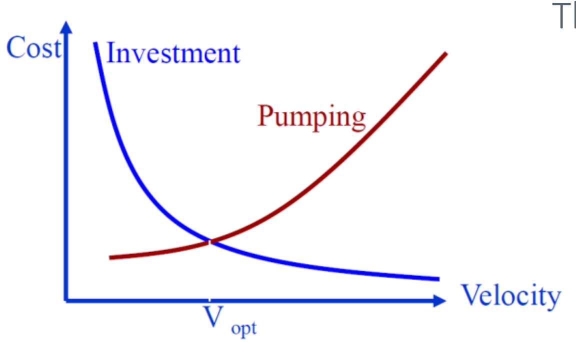
The network is an underground infrastructure to connect the heat production points to the final users.
The network is typically a **two-pipe system**. It consists in a supply and a return pipe. All the buildings are connected in parallel, so their inlet temperatures are comparable, with any variances resulting from heat dissipation along the supply pipe.
Other configurations are possible: one-pipe systems, three-pipe systems and four-pipe systems.

Supply and return pipe of a district heating network.
These are pre-insulated pipes installed approximately 1-1.5 metres deep.

The grid topology and piping layout in existing DH networks are determined by local conditions.
In general, there are three primary gid topologies: radial grid, ring grid, and meshed grid.



Network design

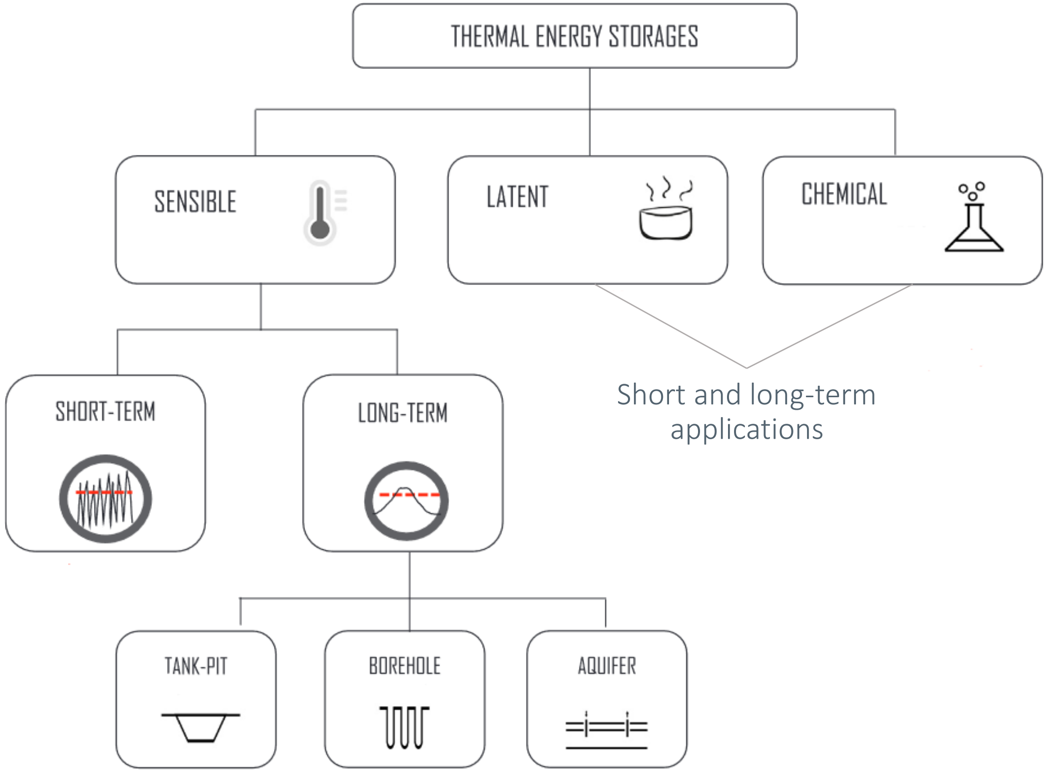


The optimal velocity is obtained by means of an economic optimization.

↓

$$D = 2 \cdot \sqrt{\frac{\dot{m}}{\pi \cdot \rho \cdot v}}$$

State of the art – Thermal Energy Storages (TES)

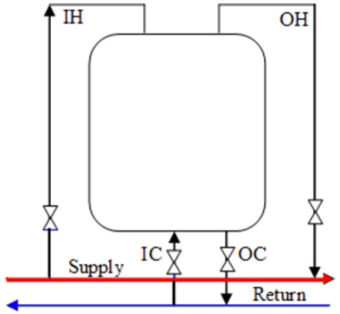


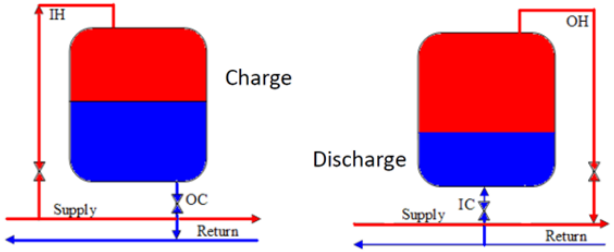
source: Guelpa, Verda - Thermal energy storage in district heating and cooling systems: A review

Main advantages of using TES in DH:

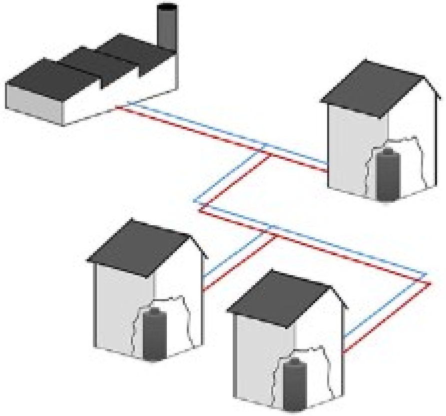
- Thermal peak shaving and valley filling
- Relieve intermittence of renewables
- Solve possible local bottlenecks
- Reduce pumping consumption
- Network management flexibility

Installation at the network level:





Installation at the buildings level:



State of the art - Pumping stations

Centralized pumping: to ensure that each user receives at least the minimum water flow rate, a minimum pressure difference between the supply and return line must be guaranteed at each substation.

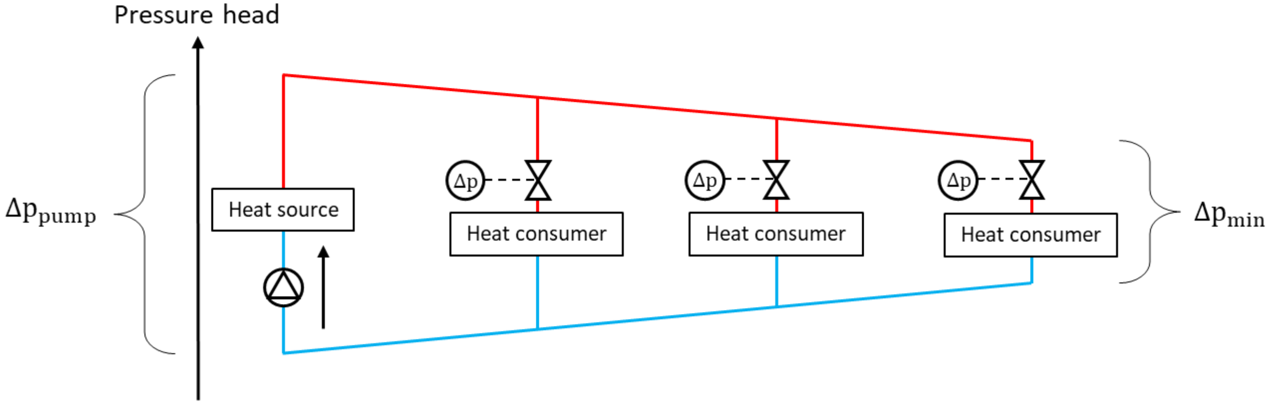
The pumping station must provide the following pressure head:

$$\Delta p_{pump} = \Delta p_s + \Delta p_r + \Delta p_{min}$$

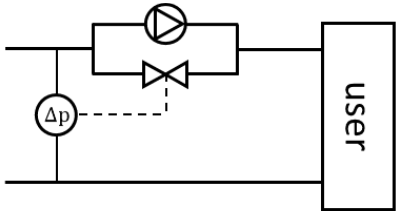
Δp_s: total pressure drop in the supply line from the pumping station to the critical substation

Δp_r: total pressure drop in the return line from the pumping station to the critical substation

Δp_{min}: minimum pressure difference required by the critical substation



Decentralized pumping: in this configuration, if the pressure difference between the supply and return line is not enough to guarantee the required water flow rate by the user, the local circulation pump is activated.



The design must be done according the following constraints:

- The pressure of the water in the network must be always above the **boiling limit**
- The pressure of the water must not exceed the **design pressure level** of the pipes.

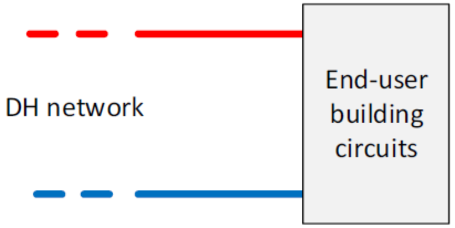
Solutions to avoid pressure issues:

- **Pressurization** of the system (dynamic or static)
- Installation of **in-line booster pumps** (in the supply and/or return line).

State of the art – Substations

Direct connection

There is no hydraulic separation between the distribution network and the user circuits: the latter must withstand the district heating pressures.



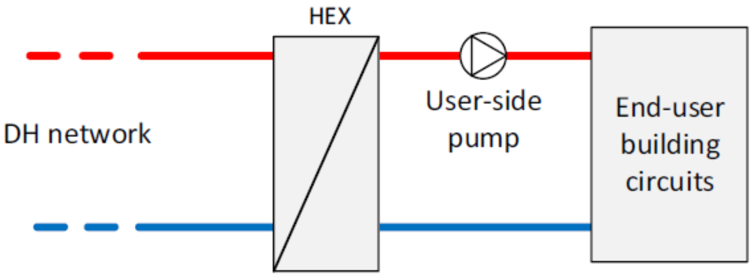
Source: www.danfoss.com

Indirect connection

The presence of a water-to-water heat exchanger (typically it is a plate heat exchanger) ensures the hydraulic separation between the distribution network and the user circuits: the pressures are decoupled.

A circulation pump on the user-side is required.

While this solution requires more installation space and is less efficient due to the temperature difference required by the heat exchanger, it increases safety and it is mandatory when network pressures are high (above PN6 or PN10).

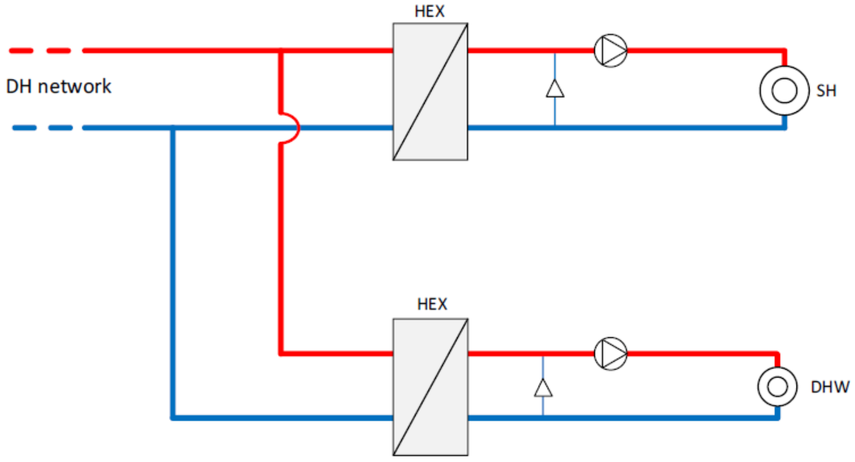


Source: www.danfoss.com

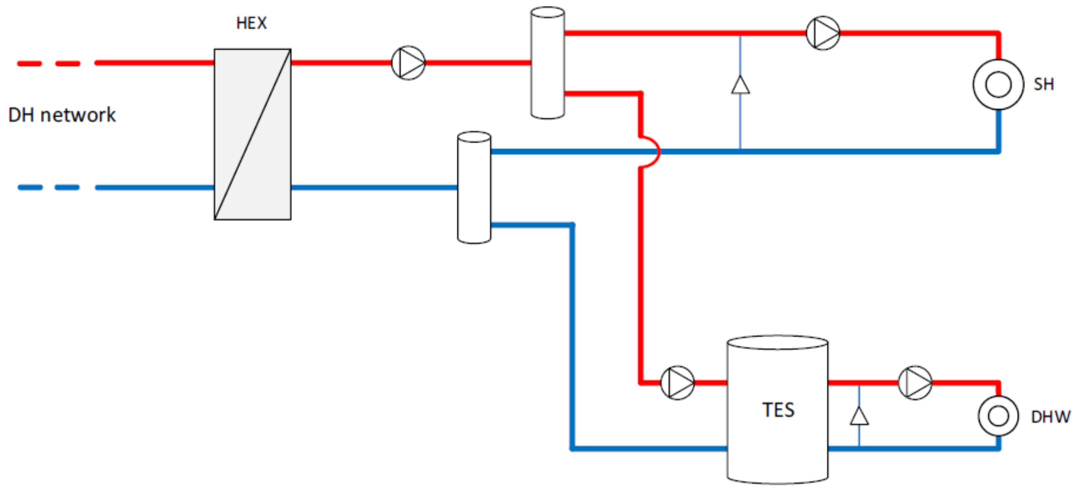
State of the art – Substations

Traditional District Heating

The supply temperature (>80°C) is high enough to directly cover both the space heating and the domestic hot water demand of the connected users.



Indirect connected substation with instantaneous production of domestic hot water.

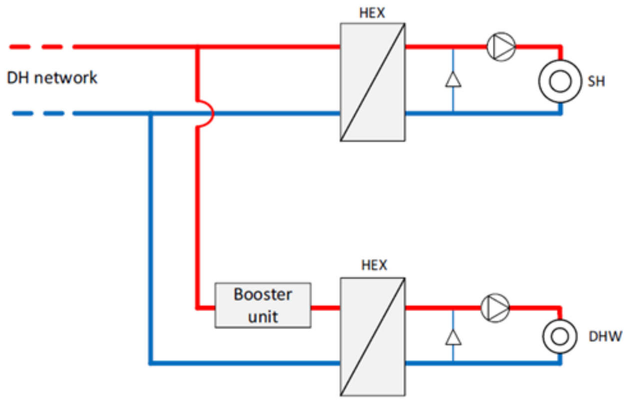


Indirect connected substation with hot water storage tank.

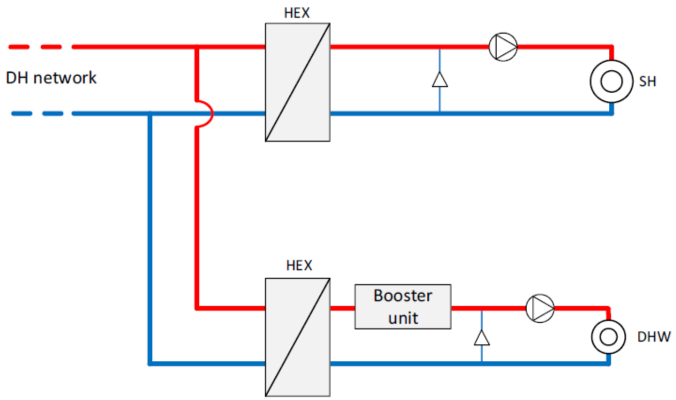
State of the art – Substations

4th Generation District Heating

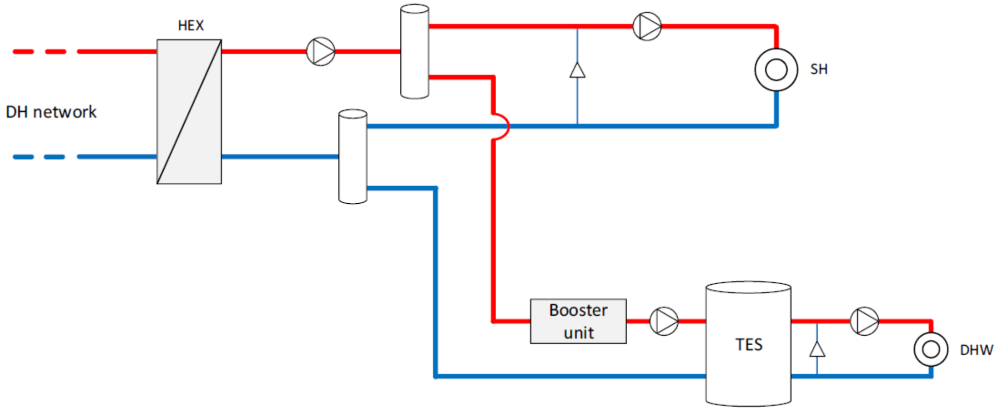
The supply temperature (50-70°C) is still high enough to directly cover the space heating demand of almost all the connected buildings. Instead, for the domestic hot water production a booster unit could be required in some cases. The latter could be an electrical resistance, a boiler or a heat pump and the installation can be made in different ways.



(a) - Booster unit on primary side of DHW heat exchanger.



(b) - Booster unit on secondary side of DHW heat exchanger.



(c) - Booster unit for hot water storage tank.

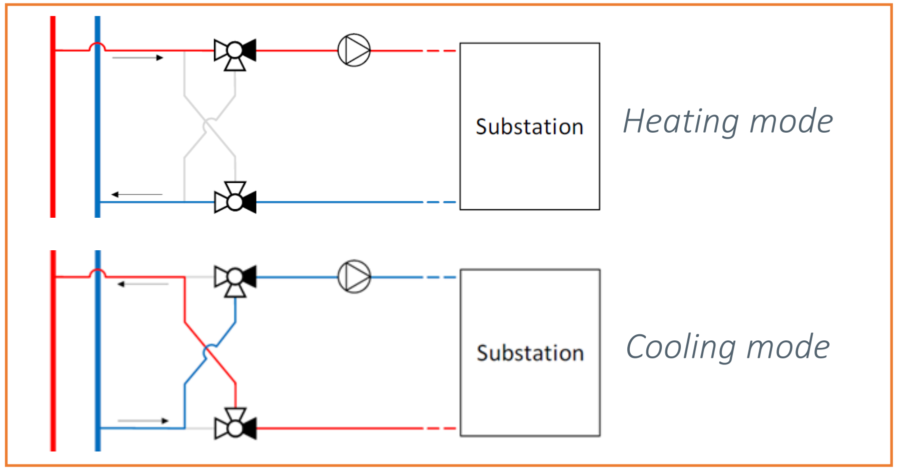
State of the art – Substations

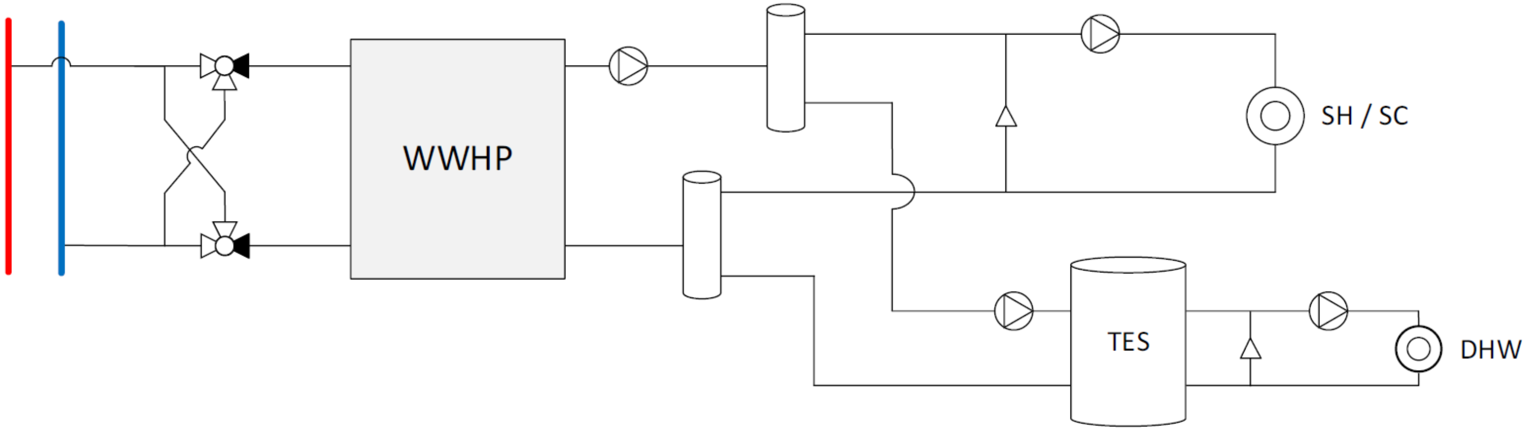
5th Generation District Heating and Cooling

With the introduction of the fifth generation, the connected users can require both heat and cold from the bidirectional network. The following nomenclature is typically adopted:

- consumer – user who absorbs heat from the network
- producer – user who supplies heat to the network
- prosumer – user who can be both consumer and producer at different times.

Since the temperatures of a 5GDHC network are not adequate to directly cover the heat and cold demands of the customers, a **water-to-water heat pump** is necessary in the substation. If the heat pump is reversible, the same substation can cover both the space heating and space cooling demand of the user. In this case a **bidirectional connection** with the network is required.

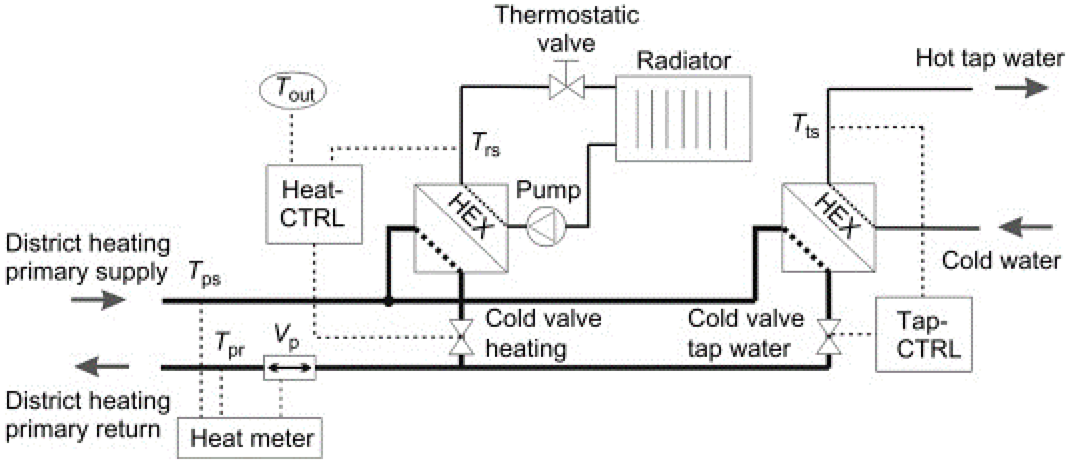




Customer relations

The customers usually pay for the heat drawn from the district heating network according to a heat rate, which normally consists of one fixed portion related to the capacity needed and one variable portion related to the amount of energy bought. In some case, there is also a portion related to water volume exchanged with the network to promote a lower return temperature from the customer substations.

For this reason, the customer substations also include a **heat meter**, based on the water constants and the measurements of the water flow and the supply-return temperature difference.



Source of the picture:
Advanced District Heating and Cooling (DHC) Systems - Robin Wiltshire, 2016

Open points and future trends

In order to improve the overall efficiency of district heating systems, several actions can be implemented.

- Lowering the DH temperatures.
- Integration of prosumers.
- Demand-side management.
- Optimization of thermal storage installation.
- Optimization of pumping system control logic.
- Analysis of fouling of the substations.

Lowering the DH temperatures →
- Reduction of thermal losses
- Greater opportunities at incorporating low-temperature renewable energy sources and low-grade waste heat
- Increase of the efficiency of heat production plants

Integration of prosumers → This concept is the basis for the 5th generation of DHC. The presence of users in cooling mode allows the network to recover heat and to transport it to users nearby, reducing the load of the heating plants.

Demand-side management → It is one of the strategies for an optimal management of DH networks. This consists in rescheduling the time when the heating systems are switched ON and OFF or modifying their settings.
The main goals are:
- peak shaving and valley filling
- meeting thermal production
- accounting for cost evolution.

Analysis of fouling of the substations → Monitoring of the substations in order to analyse the status of the heat exchangers.

Open points and future trends

Definition of efficient district heating according to article 24 of the Energy Efficiency Directive (EED).

	Required use of renewable / waste heat / fossil-fuelled CHP (*)	Minimum share of renewable energy
From 2026	50% / 50% /80% (or mix 50%)	5%
From 2035	50% / 50%	20%
From 2045	75% / 75%	40%
From 2050	100% / 100%	60%

In addition to higher adoption of renewable energy sources, such as solar thermal and geothermal energy, there is also **a significant need in increased use of waste heat** as a heat source in district heating systems.

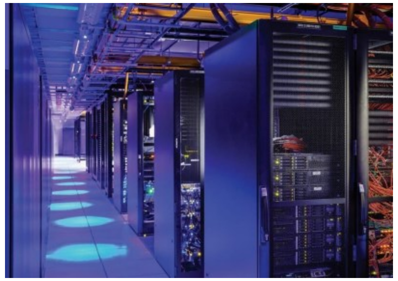
The focus on recovering waste heat into district heating systems is a key point for the coming years.

WASTE HEAT & DISTRICT HEATING

Waste heat – Overview

Waste heat is released as **by-product** of various industrial, commercial and residential processes (e.g., factories, data centres, wastewater facilities, supermarkets, and buildings) in different forms such as: combustion gases discharged to the atmosphere, heated water released into environment, heated products exiting industrial processes, and heat transfer from hot equipment surfaces.

As such, waste heat sources differ regarding the aggregate state (mainly fluid and gaseous), temperature range, and frequency of their occurrence.



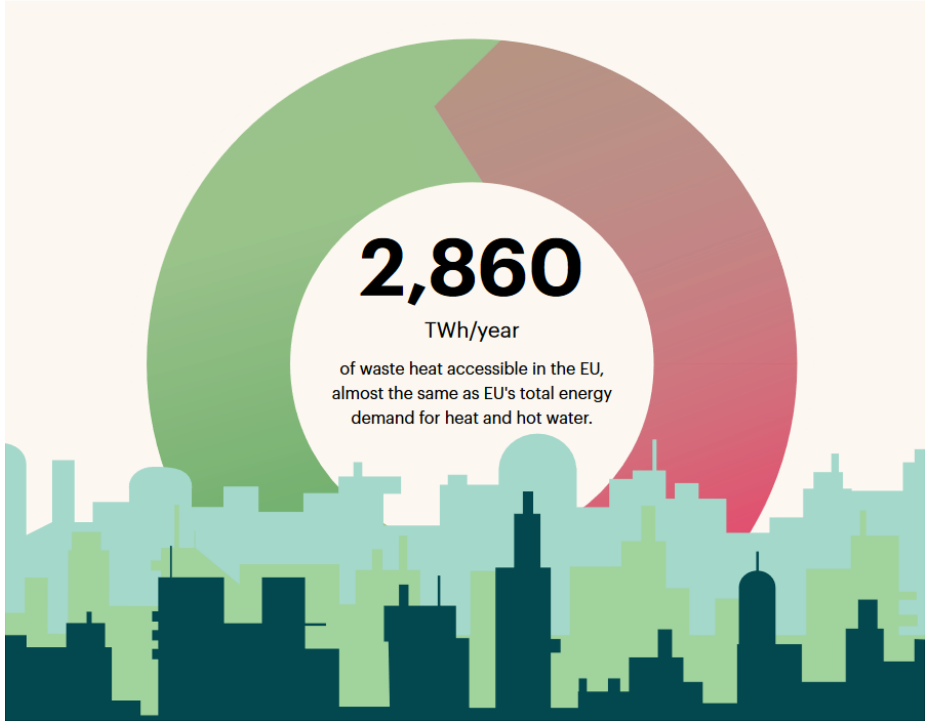
Waste heat- Overview

Why recover waste heat?

Improving energy efficiency of the system.

Using energy that would otherwise go to waste would give a productivity boost to the economy and lower energy prices for consumers.

Waste heat can replace significant amounts of electricity or gas that are otherwise needed to produce heat: recycling heat is not only an overlooked measure in the current energy crisis, but also the next frontier of the green transition.



Source: Excess heat, the world's largest untapped energy source - Danfoss

Waste heat- Overview

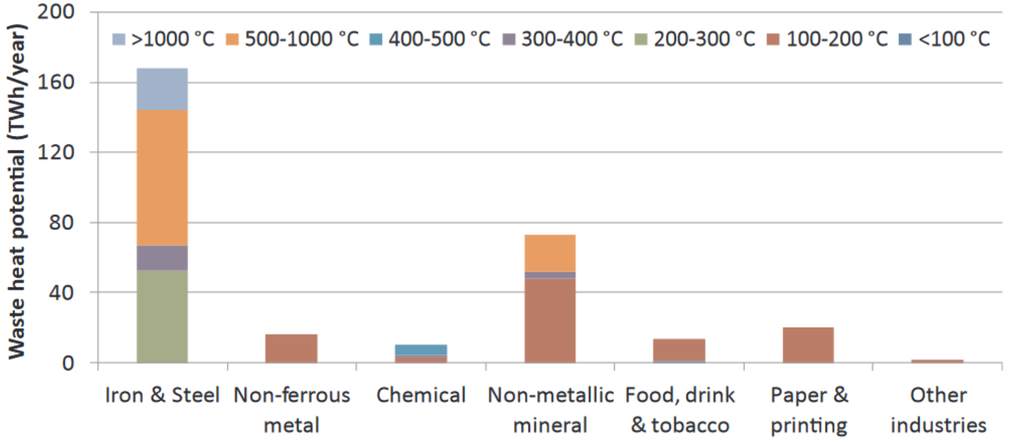
LIFE 4 HEAT RECOVERY

Industrial waste heat

The greater part is typically available at **high-temperature**, but some industrial processes are characterised also by **low-temperature** waste heat (for example waste heat from cooling towers).

The amount of industrial waste heat available and the respective thermal levels make it one of the most used heat sources to increase the efficiency of district heating networks since 1980s.

Despite this, it is mostly reused by the factory itself or in buildings in the vicinity, because both the investment costs and the thermal losses of the network are relevant since the factories are often not close to the urban centres.



Waste heat potential per industrial sector and temperature level for EU industry in 2015.

Source: Papapetrou et al - Industrial waste heat: estimation of the technically available resource in the EU per industrial sector, temperature level and country

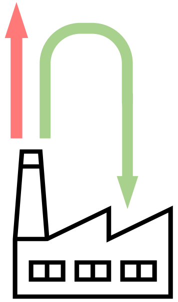
Urban waste heat

It is generated by activities in urban areas: data centres, supermarkets, waste treatment plants, space cooling systems, etc. Its thermal level is typically lower than that of industrial waste heat: it is called **low-temperature** waste heat.

The advantages of exploiting urban waste heat are considerable: the sources of heat that can be used are many and available along the network path, and the dispersion of heat through the pipes is limited because the distances between the sources and the users of the heat are small.

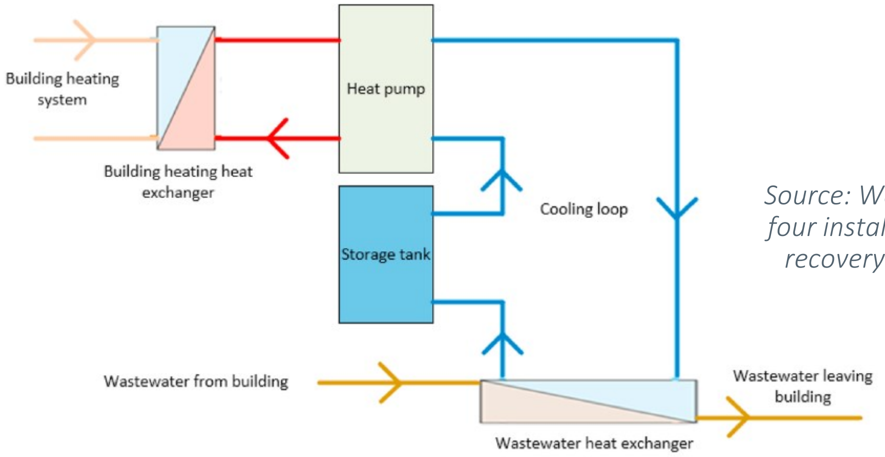
Waste heat – Overview

Heat recovery is a widely used and well-known solution, especially in the industrial sector.
The recovered heat can be reused within the same process or can be used to cover other local heat demands (space heating, domestic hot water production, etc.).
However, typically the amount of available excess heat exceeds the local needs: **the surplus will be lost into the environment as waste**.



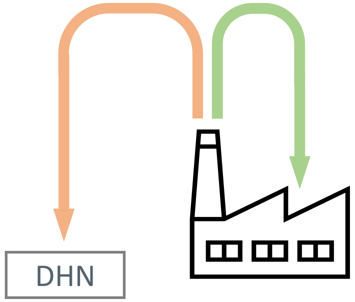
Local reutilization of excess heat.
Waste heat lost into the environment.

Wastewater heat recovery system and local reutilization.

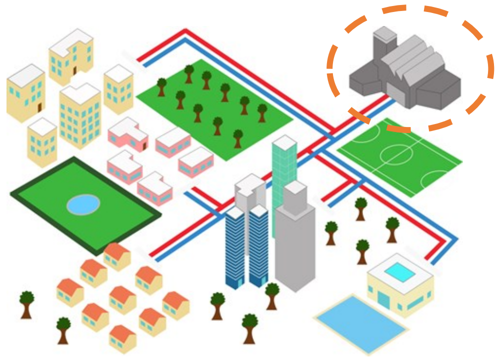


Source: Wallin - Case studies of four installed wastewater heat recovery systems in Sweden

The presence of a district heating system in the proximity of the source allows the waste heat **to be recovered and transported to other connected users** who require it.
This solution contributes significantly to the decarbonization of the district heating sector.



Local reutilization of excess heat.
Waste heat recovered into district heating.



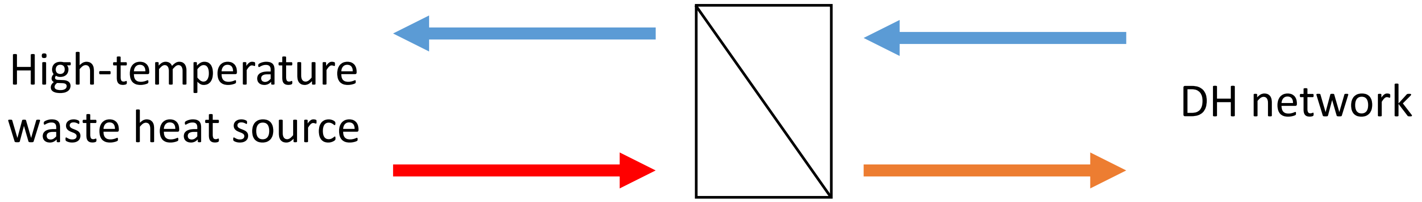
Waste heat source

LIFE 4 HEAT RECOVERY

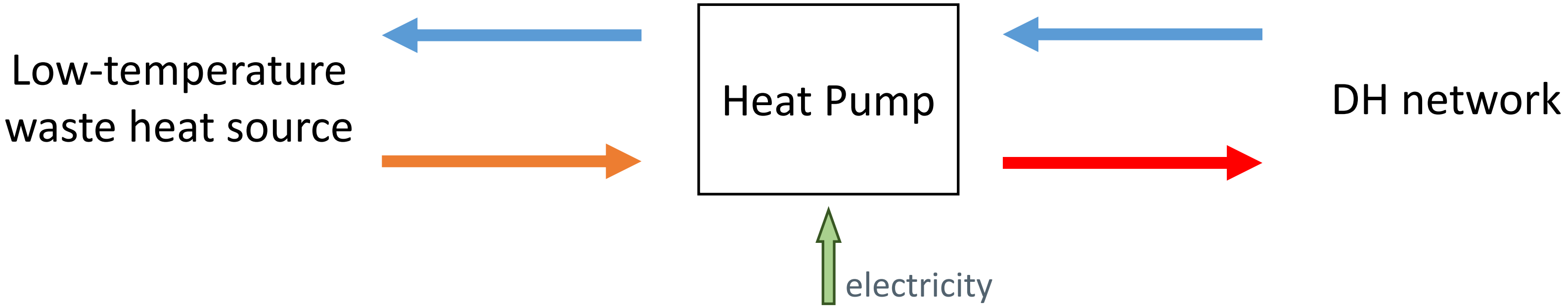
Waste heat recovery into district heating

Depending on the thermal level of the district heating network and waste heat, the recovery may take place in different ways:

- $T_{\text{waste heat}} > T_{\text{network}}$ → **direct recovery** through heat exchangers



- $T_{\text{waste heat}} < T_{\text{network}}$ → **heat pump based substation** to reach the temperature of the network



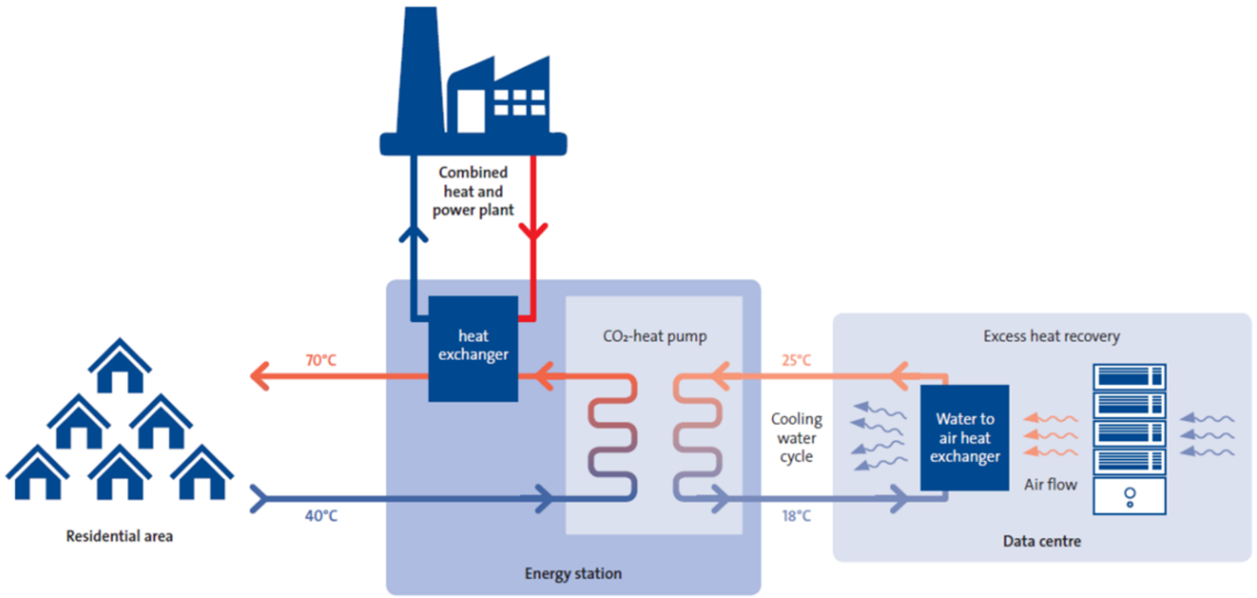
Waste heat recovery into district heating - Examples

Excess heat recovery from data centre in Braunschweig, Germany.

LIFE 4 HEAT RECOVERY

The temperature required by the traditional district heating network (supply temperature of about 70 °C) is reached through a series system.

- **Low-temperature waste heat recovery:** the return line of the network is firstly pre-heated by a CO2 heat pump using the excess heat from the cooling system of a data center as a source.
- **High-temperature waste heat recovery:** the pre-heated water is further heated by a heat exchanger which recovers heat from a combined heat and power plant. The use of the heat exchanger as a "topping system" allows operating the heat pump at a lower condenser temperature and hence at a higher efficiency.

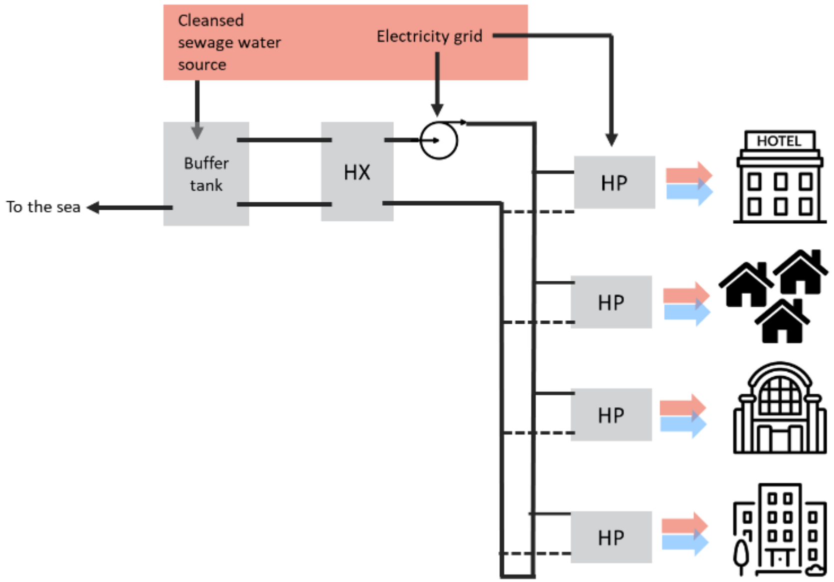


Source: ReUseHeat - Transfer of best practices and lessons learnt from urban waste heat recovery investments.

Waste heat recovery into district heating - Examples

Low-temperature waste heat recovery from sewage water in Nice, France.

In this case the low-temperature waste heat is directly recovered into the district heating system through a plate heat exchanger.
This is possible since it is a low-temperature network: each end-user is equipped with its own decentralized heat pump to upgrade the temperature level.
The presence of the buffer tank allows to bridge the temporal mismatch between the availability of waste heat and the heat demand on the network.



Source: ReUseHeat - Transfer of best practices and lessons learnt from urban waste heat recovery investments.

THE LIFE4HeatRecovery PROJECT

LIFE4HeatRecovery – Project Overview

LIFE4HeatRecovery demonstrates the recovery of **urban waste heat** available **at low temperature** (< 40 °C) in highly efficient district heating and cooling networks operated at conventional or low temperature.

The project includes:

- 3 demonstration cases:
    - Ospitaletto, Italy: heat recovery from the cooling system of a foundry
    - Aalborg, Denmark: heat recovery from a data center
    - Heerlen, the Netherlands: heat recovery from the cooling system of a foundry

- 3 partner cities where the implementation of waste heat recovery into the existing district heating network would be valuable:
    - Castegnato, Italy
    - Plymouth, United Kingdom
    - Brunssum, the Netherlands

More information can be found at the project website: https://www.life4heatrecovery.eu/

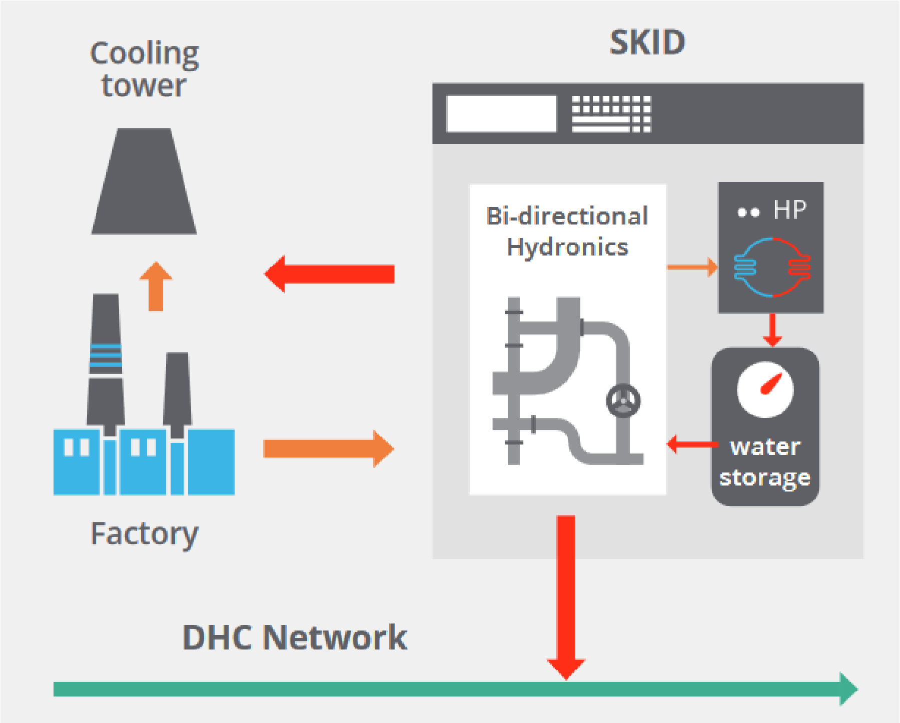
Life 4 Heat Recovery – Waste heat recovery solutions

LIFE 4 HEAT RECOVERY

The main idea is to recover low-temperature waste heat from sources located in urban areas and in the proximity of existing district heating networks (both high- and low-temperature network).

The heat recovery is performed by specific substations ensuring the supply temperature required by the network. Thanks to the **bi-directional connection**, the substation can also meet the local heating needs extracting heat from the network when the waste heat is not available, or it is insufficient.

Prefabricated SKIDs will be designed and manufactured, including all necessary hydraulics, electric and electronic components. Thanks to this strategy, design and installation time and errors are minimised, while manufacturing cost reduction is pursued.



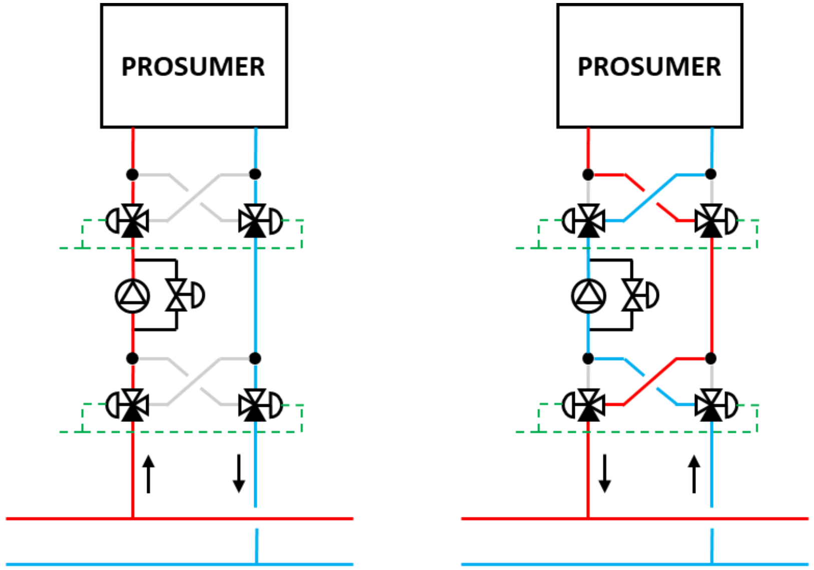
THE LIFE4HeatRecovery PROJECT

General design solutions

LIFE4HeatRecovery – Waste heat recovery solutions

Bidirectional connection with the network

Bidirectional connection between the user and the network realised by using two pairs of three-way valves. As an alternative, each three-way valve can be replaced by a pair of two-way valves.



a) Consumer mode b) Producer mode

The prosumer is connected to both pipes of the district heating network:

Consumer mode: supply-to-return connection. The user withdraws water from the supply line and returns it into the return line at a lower temperature.

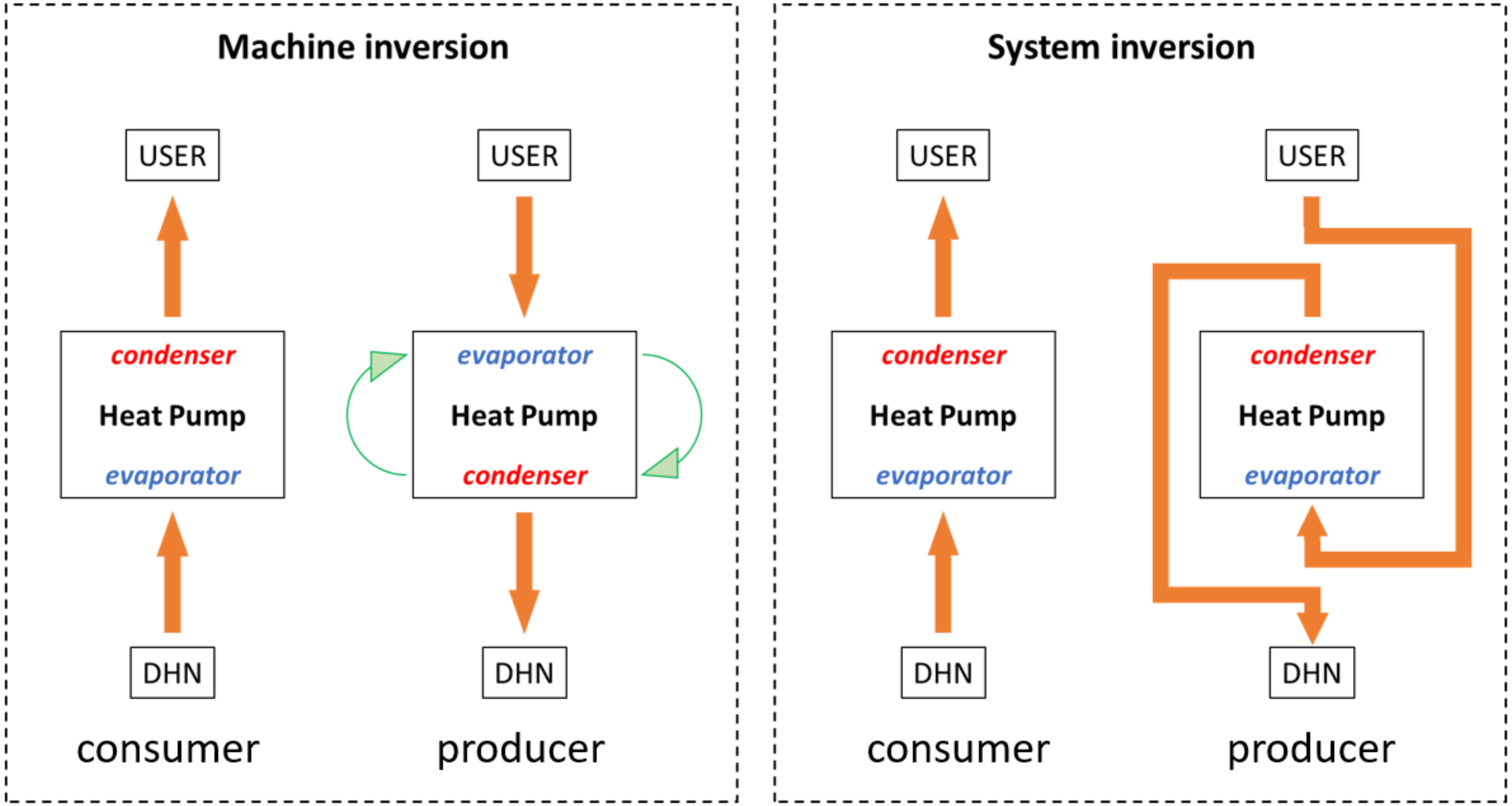
Producer mode: return-to-supply connection. The user withdraws water from the return line and returns it into the supply line at a higher temperature.

Other solutions involving connection to a single pipe (i.e., supply-to-supply or return-to-return connection) are also possible.

The bypass branch on the circulation pump makes it possible to keep the pump switched off if the pressure difference between the withdrawal and the returning pipe is such that the required flow rate is ensured.

LIFE4HeatRecovery – Waste heat recovery solutions

Reversibility of HP-skid



The reversibility of a HP-skid can be achieved in two different ways.

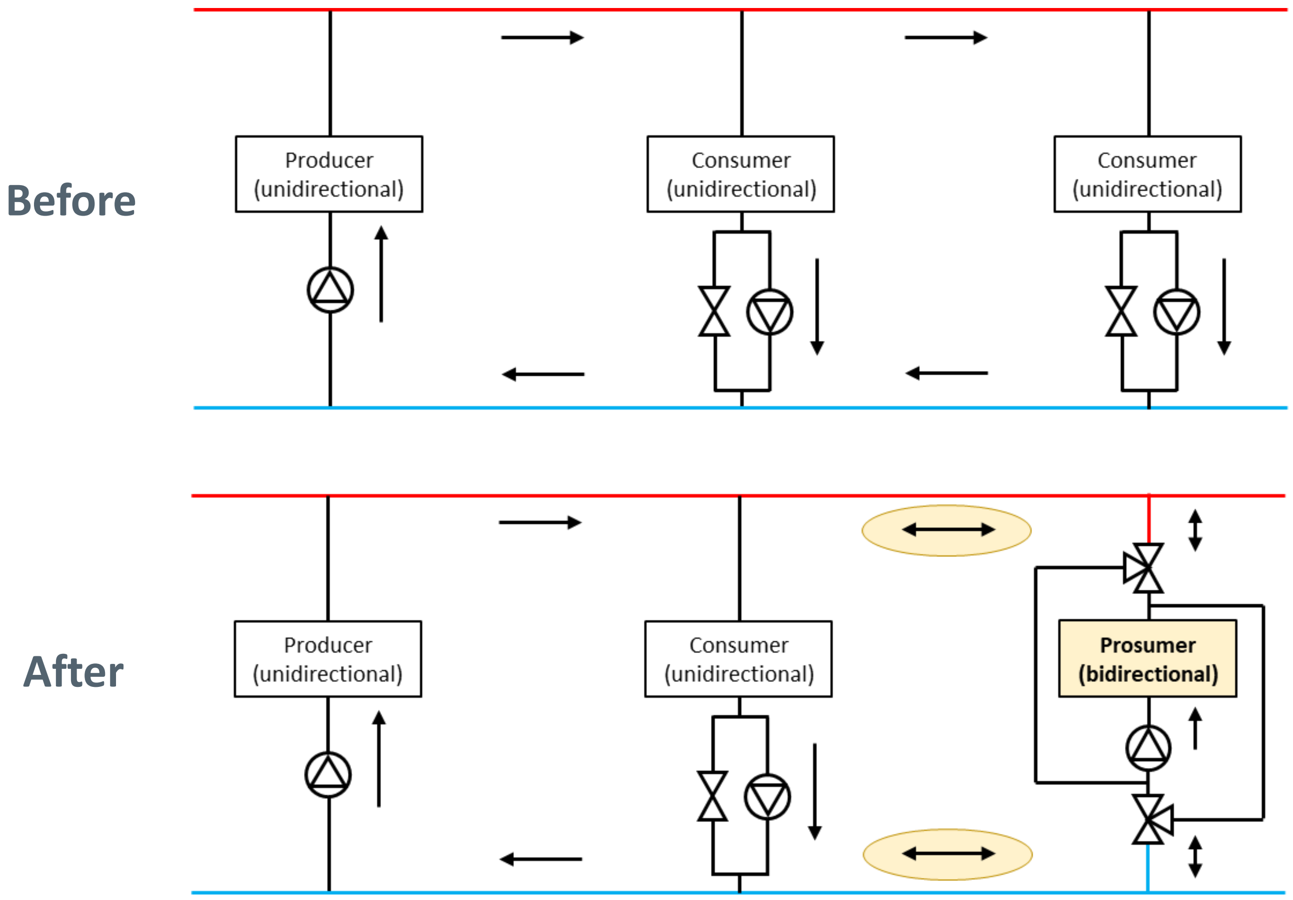
Machine inversion: reversible heat pumps are installed in the skid. Operation inversion typically requires some switching time.

System inversion: a hydraulic configuration capable of reversing the heat source and load of the heat pumps is installed. This might allow smoother operation. System hydraulics can also be used to combine multiple HP modules and adjust inlet-outlet temperature differences.

LIFE4HeatRecovery – Waste heat recovery solutions

LIFE 4 HEAT RECOVERY

Integration of a prosumer into a network



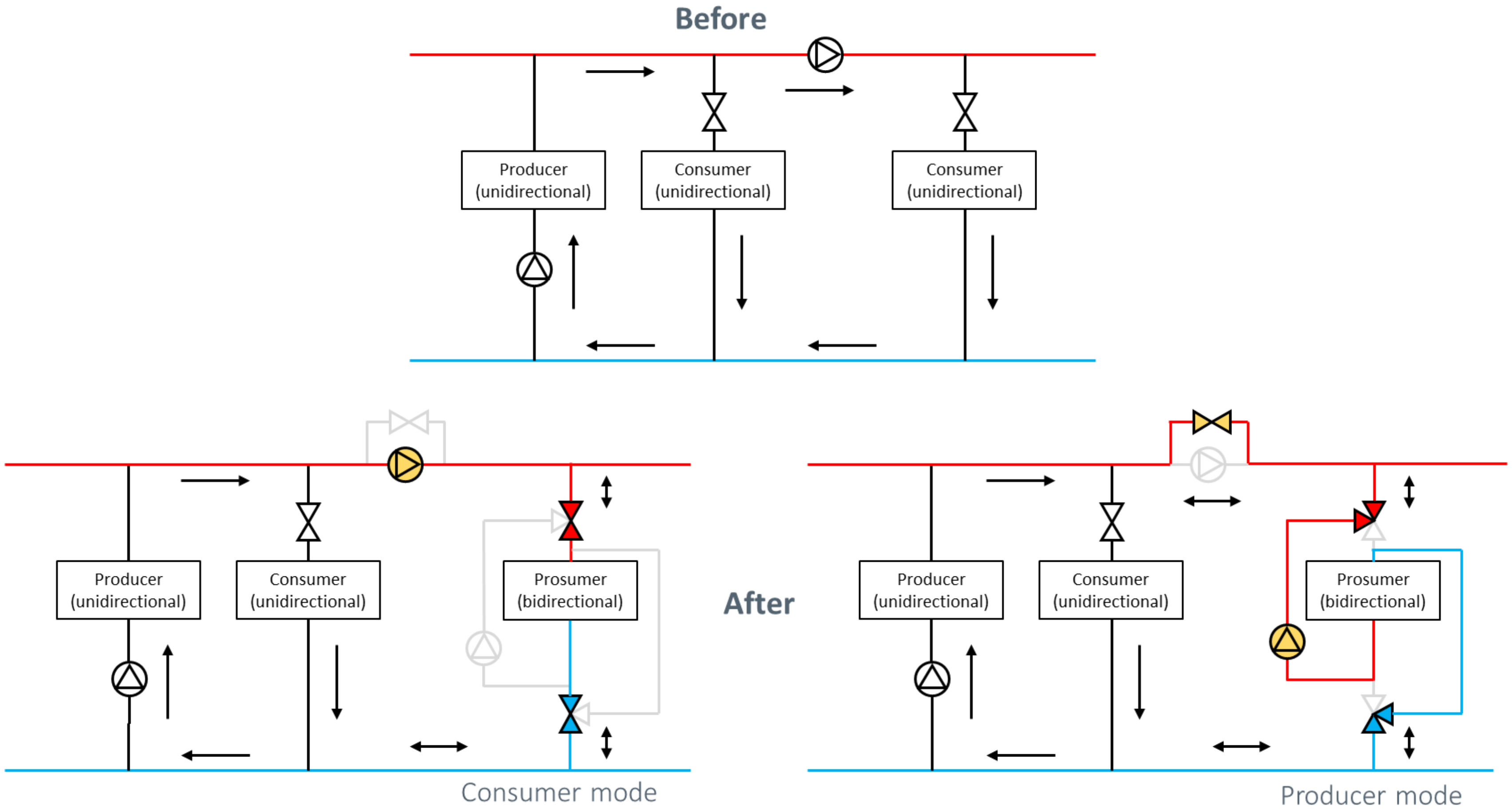
In typical configurations with a few centralized producers and fixed consumers, the flow direction in each network section is fixed.

The conversion of a consumer into a prosumer connected to the supply and the return pipe requires these network sections to become bidirectional.

If the network is characterized by decentralized pumping (i.e., each user has its own circulation pump), then this aspect is not critical and conversion is easier.

LIFE4HeatRecovery – Waste heat recovery solutions

Integration of a prosumer into the network



If, instead, the network section is characterized by centralized pumping with in-line booster circulation pumps, a bypass branch is needed in order to achieve the bidirectionality.

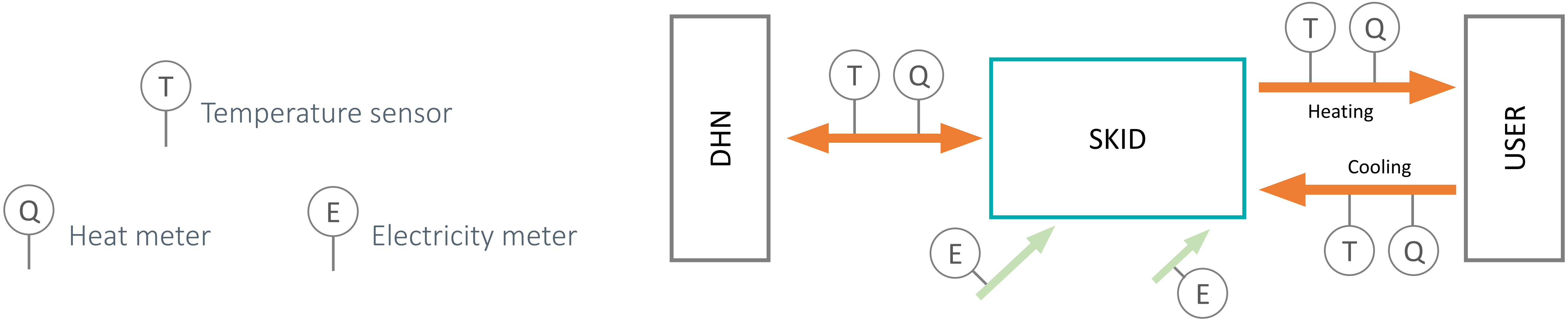
LIFE4HeatRecovery – Waste heat recovery solutions

Monitoring

Monitoring activities of the waste heat recovery solutions installed at the different demo cases are also planned as part of the project.

The main goals are:

- Verify the ability of the skid to recover heat into the network at the required temperature
- Verify the ability of the skid to meet the heating and/or cooling needs of the user
- Evaluate the perfomance of the heat pumps installed in the skid
- Evaluate the overall performance of the skid



THE LIFE4HeatRecovery PROJECT

Focus on demo cases

LIFE4HeatRecovery – Waste heat recovery solutions

LIFE 4 HEAT RECOVERY

The optimal hydraulic configuration (i.e., the one that maximizes the passive sharing of heat) of the waste heat recovery substation varies depending on **the combination of the thermal levels** of:

- waste heat
- district heating network
- user thermal demand

Examples developed for the three demo cases of LIFE4HeatRecovery are shown below.

Passive sharing: heat transferred without operating the heat pump.

Theoretical passive sharing: the maximum amount of heat which can be transferred passively according to the thermal level conditions.

temperature ↑	Ospitaletto, Italy	Aalborg, Denmark	Heerlen, the Netherlands
High	Local heating demand (45-50 °C)	District heating (>60 °C)	Local heating demand (55-65 °C)
Middle	Waste heat (25-30 °C)	Local heating demand (50-60 °C)	Waste heat (25-40 °C)
Low	District heating (15 °C)	Waste heat (25-60 °C)	District heating (30 °C)

THE LIFE4HeatRecovery PROJECT

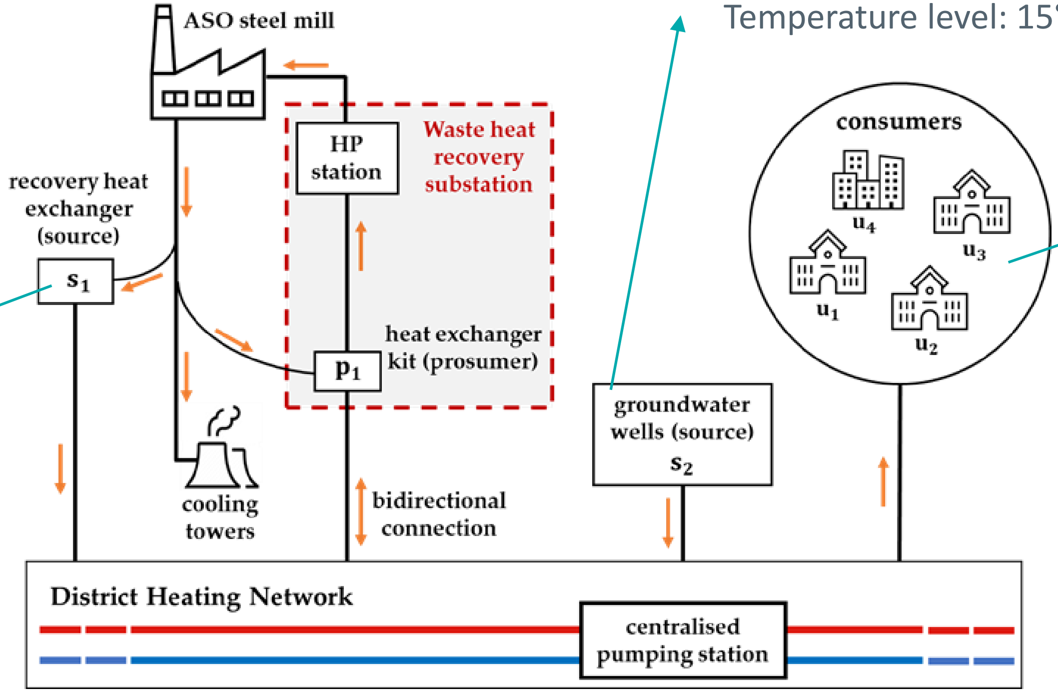
Focus on the demo cases: Ospitaletto, Italy

LIFE4HeatRecovery – Waste heat recovery solutions

Ospitaletto, Italy – Heat recovery from the cooling system of a foundry into a cold network

The groundwater wells are exploited as heat source when the waste heat from the foundry is not available. Temperature level: 15°C

Each end-user is equipped with a decentralized HP-based substation



Already existing waste heat recovery heat exchanger. Temperature level: 25-30 °C

Local heating demand (45-50 °C)

Waste heat (25-30 °C)

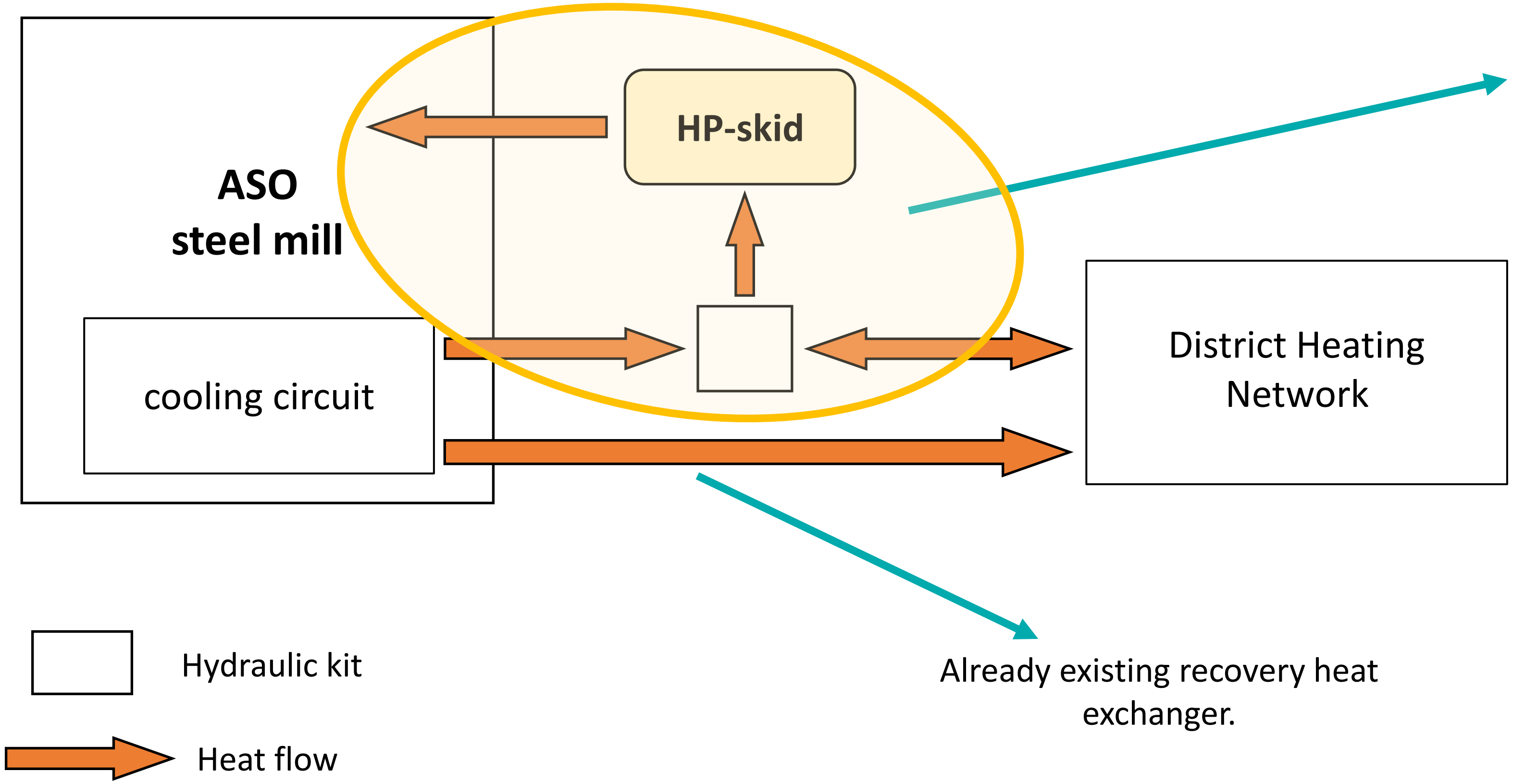
District heating (15 °C)

LIFE4HeatRecovery – Waste heat recovery solutions

Ospitaletto, Italy – Waste heat recovery system description

Waste Heat Recovery Substation

- monodirectional HP-skid providing **only heat** to the user.
- hydraulic kit comprising a bidirectional connection with the network.
- partially contribute to the cooling effect.



Local heating demand (45-50 °C)

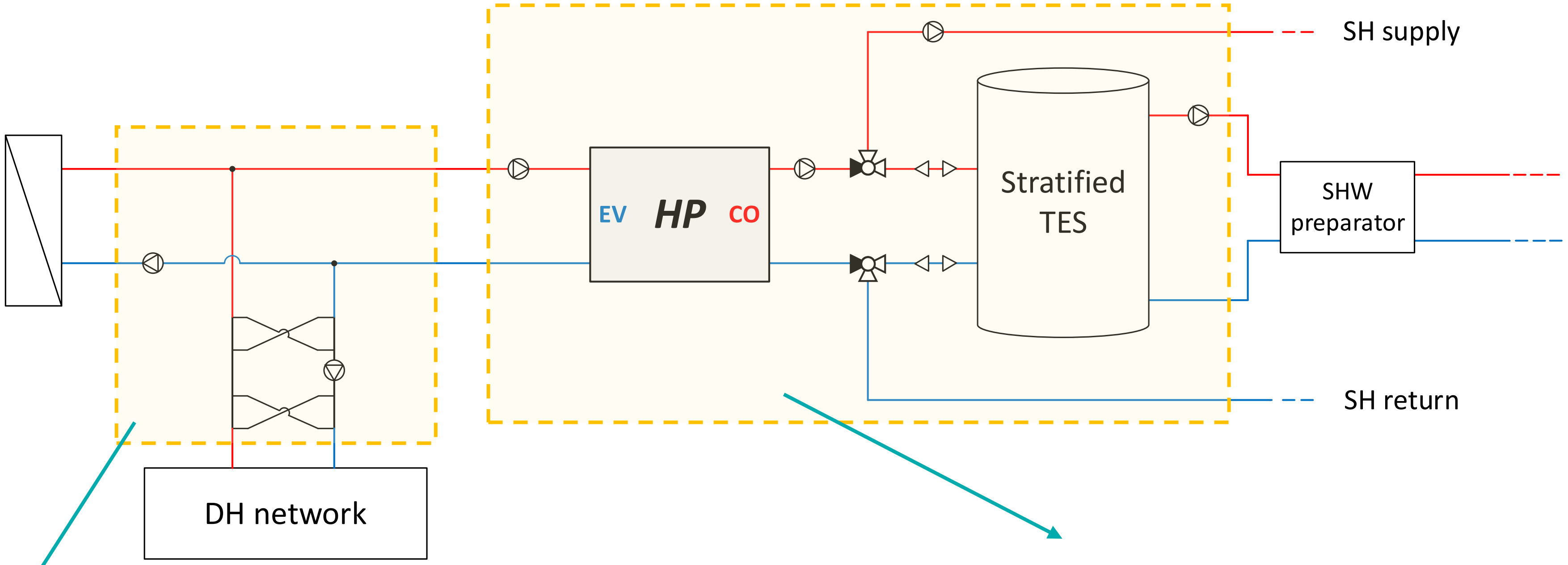
Waste heat (25-30 °C)

District heating (15 °C)

LIFE4HeatRecovery – Waste heat recovery solutions

LIFE 4 HEAT RECOVERY

Ospitaletto, Italy – Substation configuration



Waste heat recovery heat exchanger.
It allows waste heat to be recovered from the cooling towers circuit, also ensuring hydraulic separation.

Hydraulic kit.
It represents the connection point between the WH heat exchanger, the HP station and the district heating network. The connection with the latter is bi-directional.

Heat Pump skid.
It consists of a water-to-water heat pump to ensure the thermal level desired by the user and a stratified thermal energy storage.

Passive sharing: 0 %

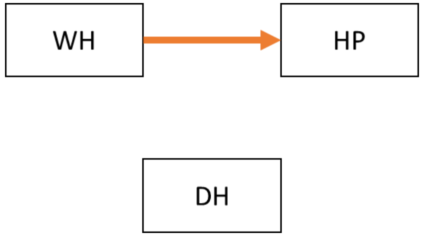
LIFE4HeatRecovery – Waste heat recovery solutions

LIFE 4 HEAT RECOVERY

Ospitaletto, Italy – Operating schemes

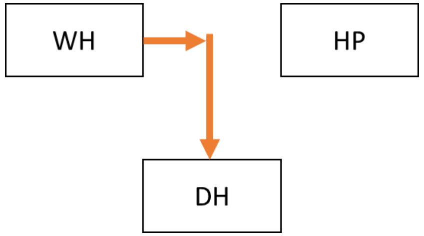
Stand-alone / Disconnected

If the power required by the heat pump on the source side is equal to the power available on the waste heat side, the skid has no interaction with the district heating network.



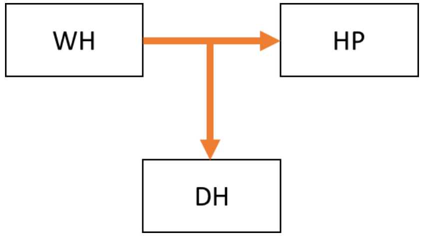
Producer

If waste heat is available and the heat pump is not in operation, all the heat is recovered within the district heating network.



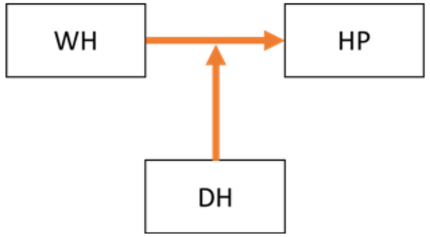
Hybrid: self-consumption and producer

When the available waste heat exceeds local demand, all excess is supplied to the district heating network. Therefore, priority is given to self-consumption.



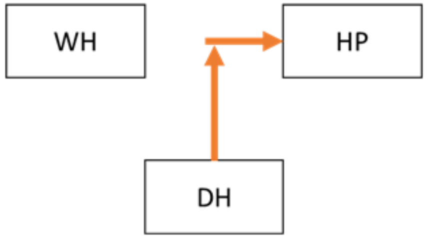
Hybrid: self-consumption and consumer

When the available waste heat is not sufficient to cover all the local heat demand, the residual is withdrawn from the network.



Consumer

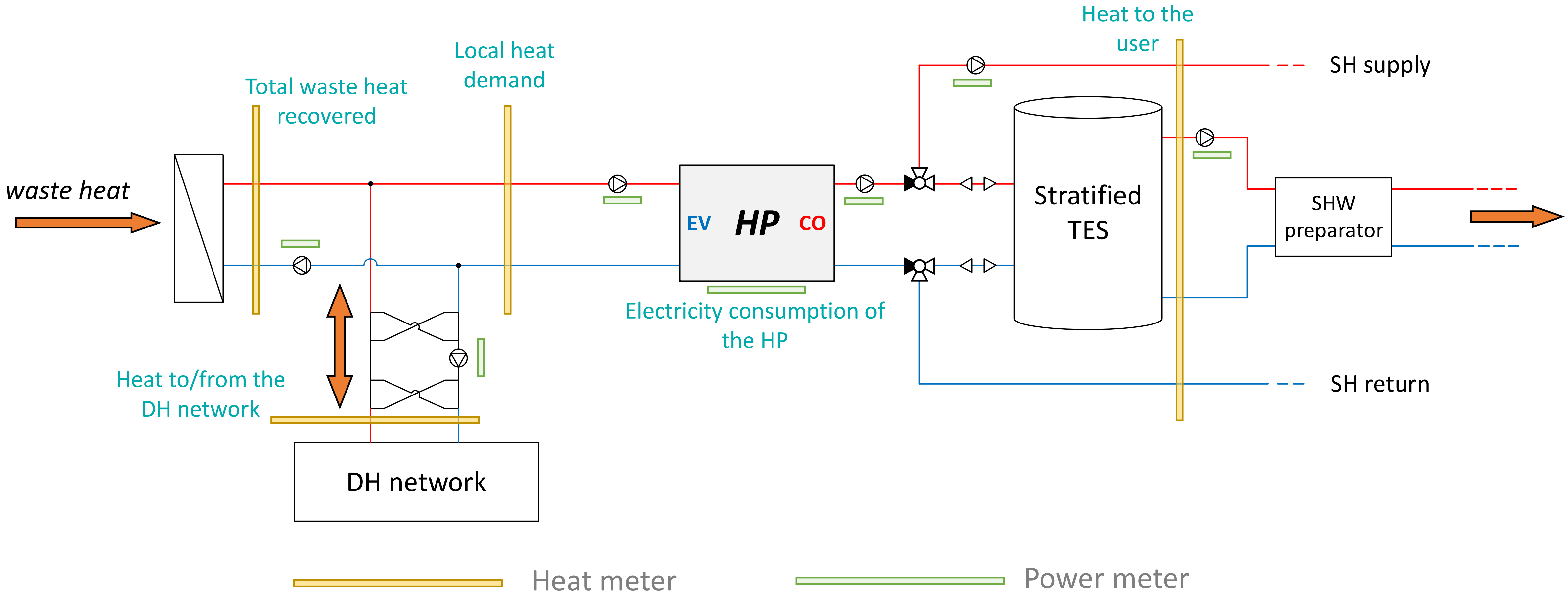
If there is no waste heat and the heat pump is operating, all the required heat is supplied by the district heating.



LIFE4HeatRecovery – Waste heat recovery solutions

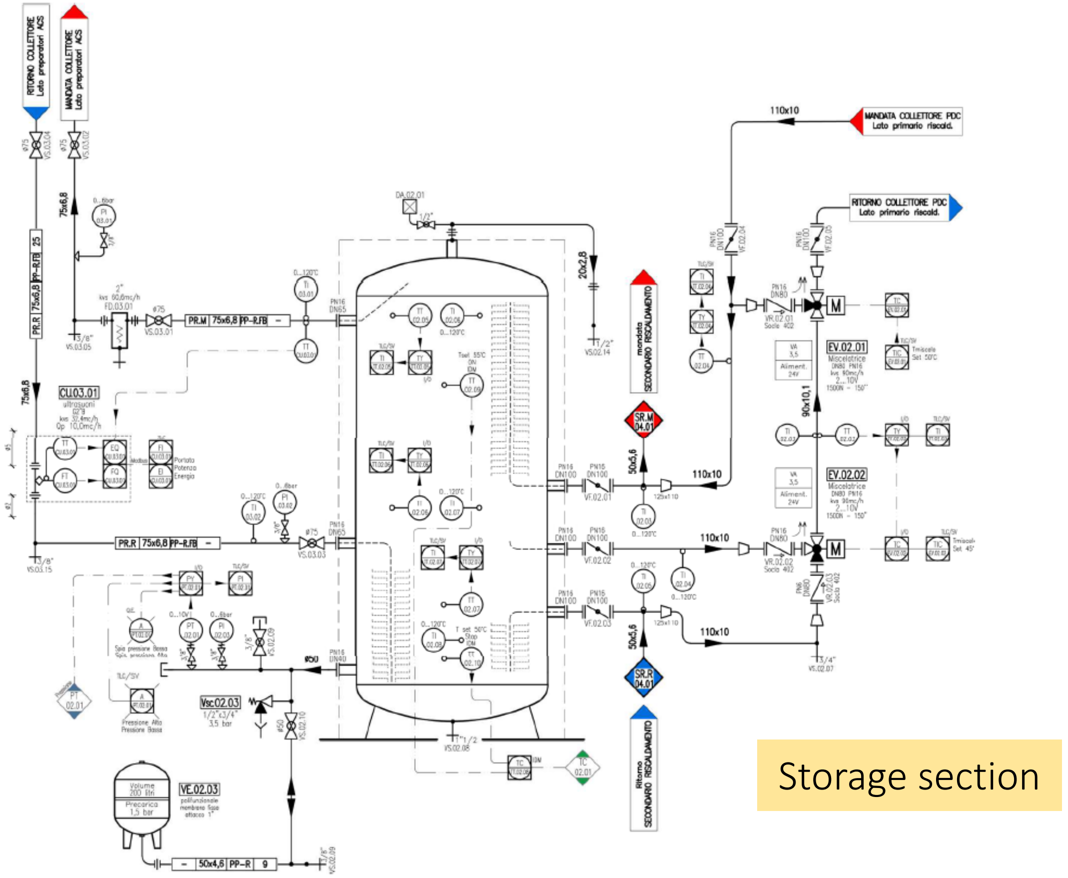
LIFE 4 HEAT RECOVERY

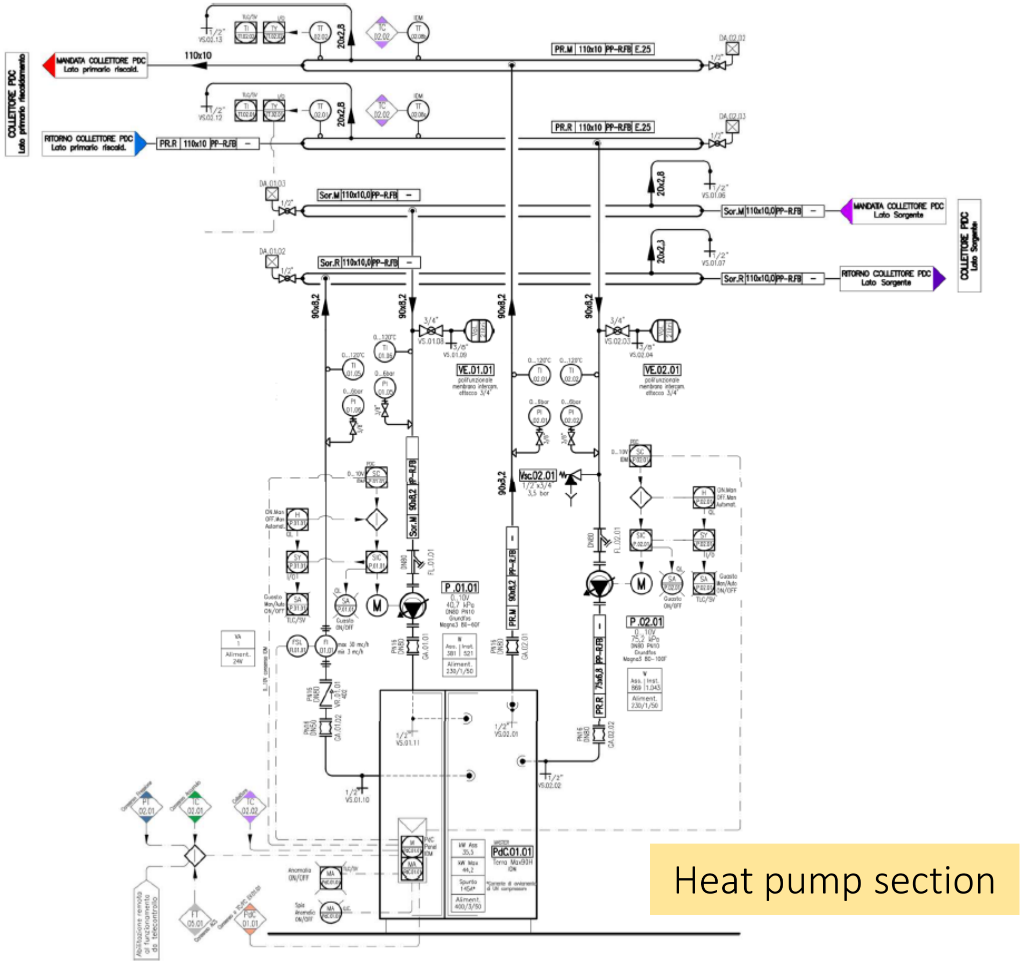
Ospitaletto, Italy – Monitoring system



LIFE4HeatRecovery – Waste heat recovery solutions

Ospitaletto, Italy – Monitoring system

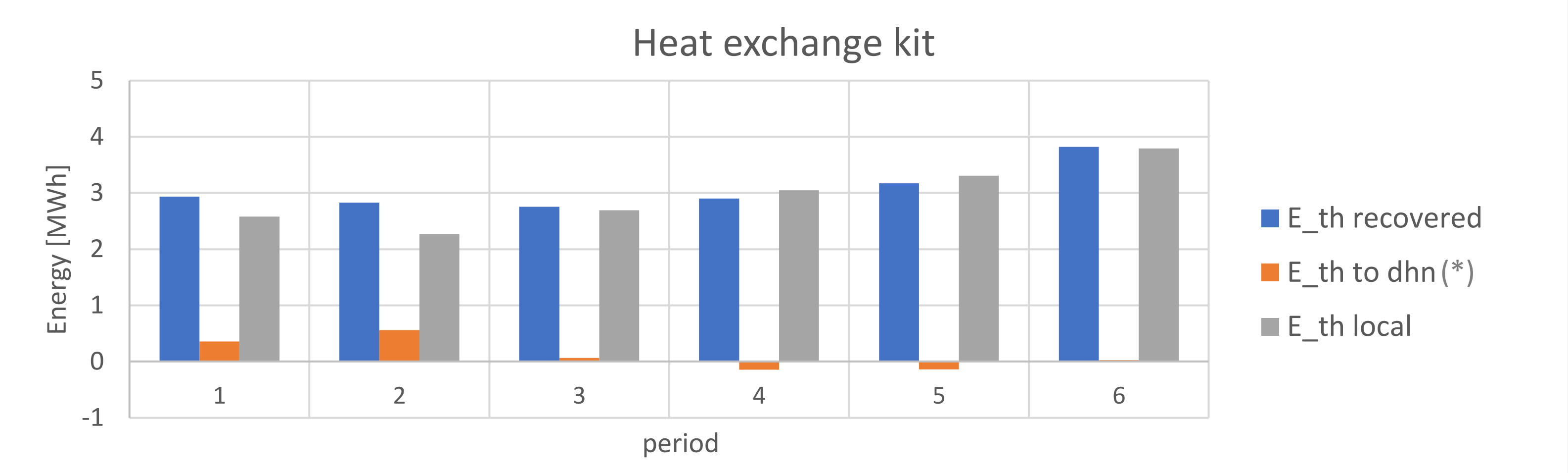


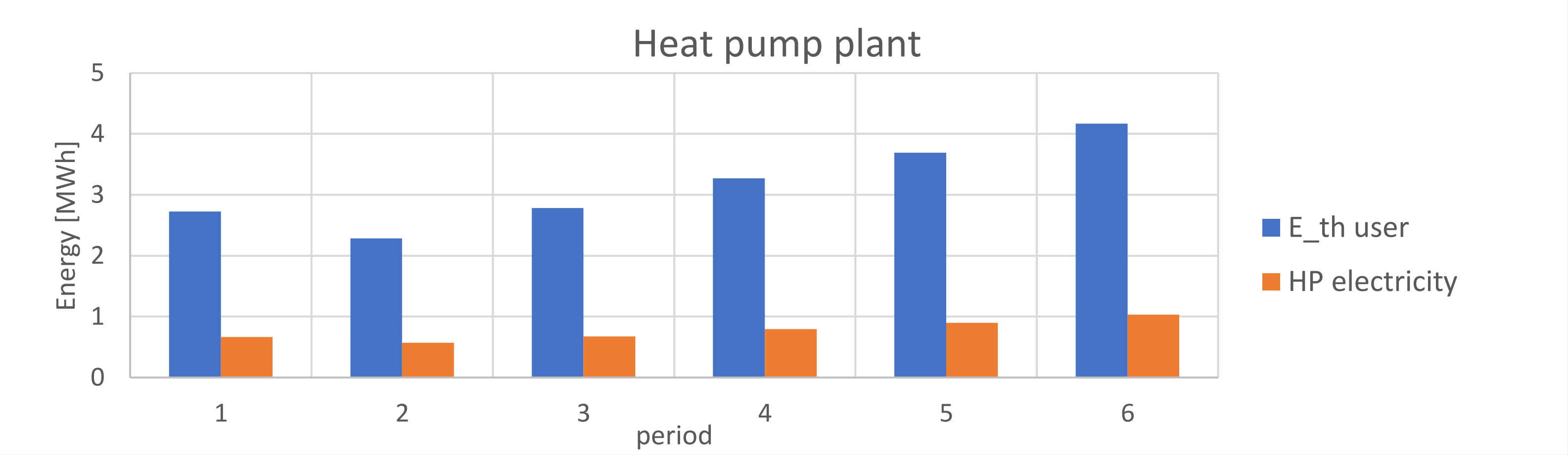


LIFE4HeatRecovery – Waste heat recovery solutions

Ospitaletto, Italy – Monitoring results

Period	Start	End	N days
1	16.02.2024	23.02.24	7
2	23.02.2024	01.03.2024	7
3	01.03.2024	08.03.2024	7
4	08.03.2024	15.03.2024	7
5	15.03.2024	25.03.2024	10
6	25.03.2024	04.04.2024	10





(*) For the heat exchanged with the DH network:
- positive values denotes heat recovered in the network
- negative values denotes heat extracted from the network

LIFE4HeatRecovery – Waste heat recovery solutions

Ospitaletto, Italy – Monitoring results

Monitoring period		1	2	3	4	5	6
E_th recovered	MWh	2.93	2.82	2.75	2.90	3.1	3.81
E_th to dhn	MWh	0.35	0.55	0.06	-0.14	-0.13	0.02
E_th local	MWh	2.57	2.26	2.69	3.05	3.30	3.79
E_th user	MWh	2.72	2.28	2.78	3.26	3.69	4.16
HP electricity	MWh	0.66	0.57	0.67	0.79	0.9	1.03
COP HP-tank	**-**	**4.11**	**4.00**	**4.13**	**4.12**	**4.10**	**4.04**
COP skid	**-**	**3.28**	**3.04**	**3.20**	**3.30**	**3.20**	**3.24**

The COP of the HP-tank system is computed as the ratio of the heat supplied to the user to the electricity consumption of the heat pump. Thus, the pumping electricity consumption is not taken into account.
COP skid includes pumping consumptions excluding those towards DH and for user distribution.

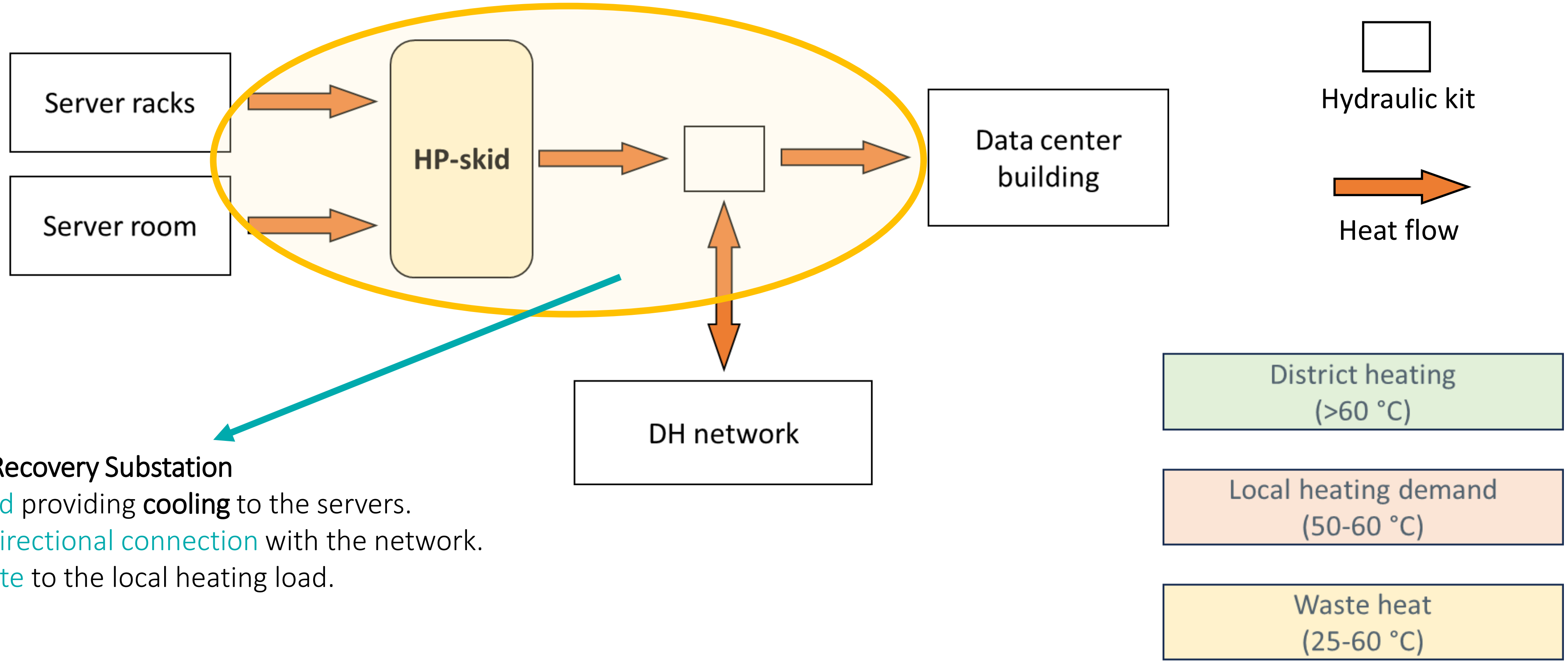
THE LIFE4HeatRecovery PROJECT

Focus on the demo cases: Aalborg, Denmark

LIFE4HeatRecovery – Waste heat recovery solutions

Aalborg, Denmark – Heat recovery from a data center into a medium-high temperature network

Waste heat recovery system description

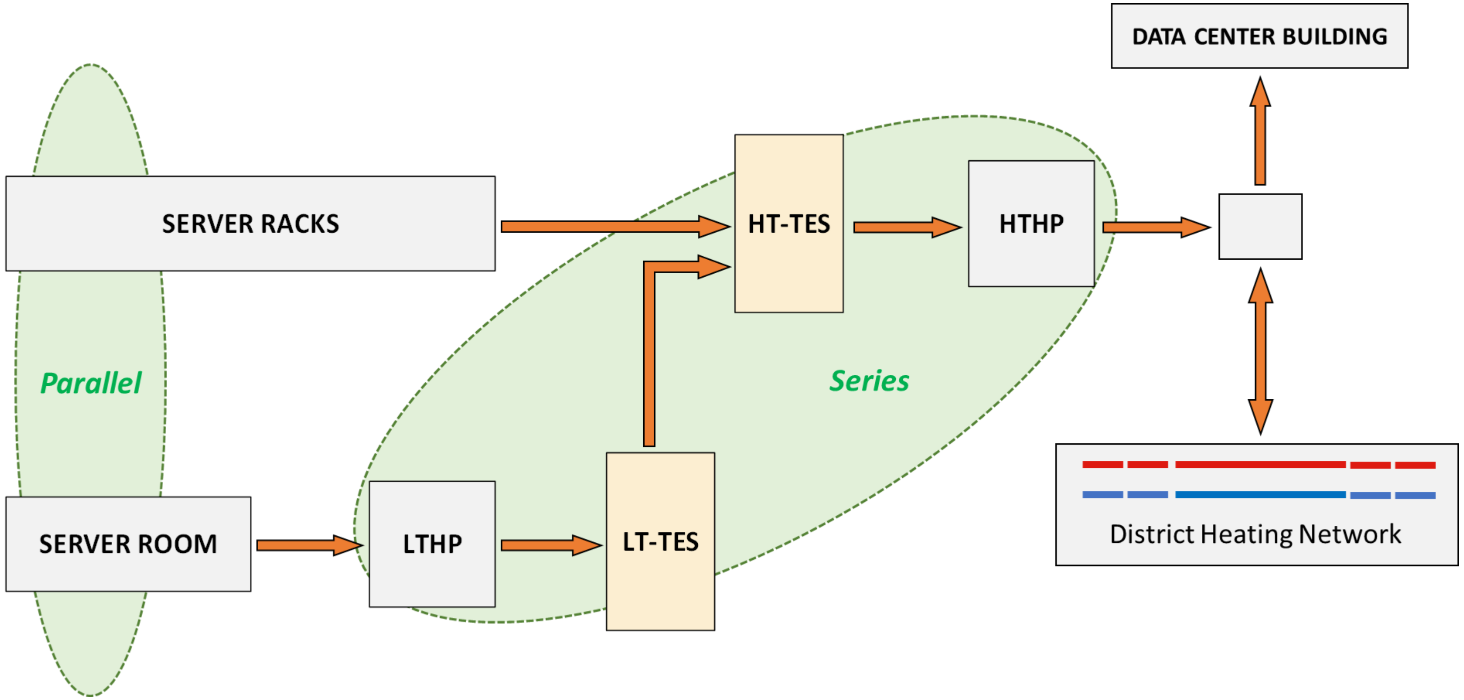


Waste Heat Recovery Substation

- monodirectional HP-skid providing **cooling** to the servers.
- hydraulic kit comprising a bidirectional connection with the network.
- partially contribute to the local heating load.

LIFE4HeatRecovery – Waste heat recovery solutions

Aalborg, Denmark – Substation configuration, full concept

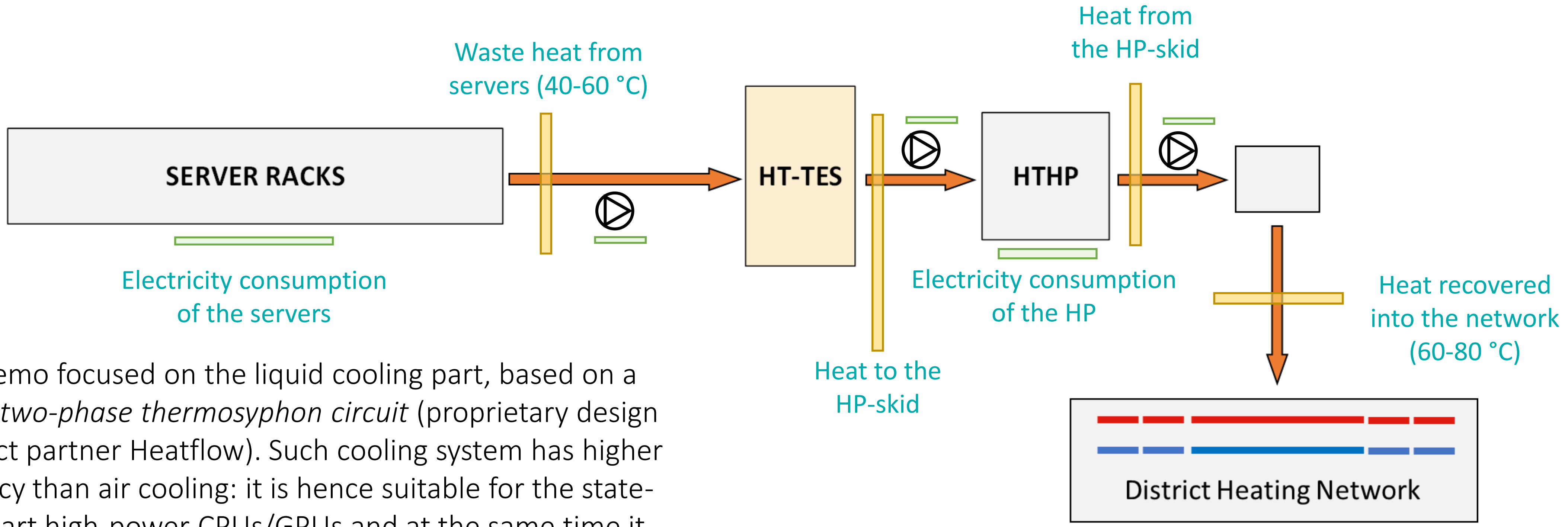


- The aims are to cool the server racks by keeping them at a temperature of 40-60 °C and to keep the server room at a temperature of approx. 20 °C.
- The waste heat recovery substation was designed to recover heat both from the *liquid-cooling* system of the server racks and from the *air-cooling* system of the server room (***parallel system***). Since the heat from the server rooms has a significantly lower thermal level than that from the racks, the skid was conceived as a cascade system, with two dedicated heat pumps and storage tanks (***series system***).
- Two storage units decouple the waste heat recovery process from the cooling process of the user, which also makes it possible to compensate for possible mismatches between the required cooling power and the cooling power provided by the heat pumps.
- The implemented demo only included heat recovery from the liquid-cooling system of racks.

LIFE4HeatRecovery – Waste heat recovery solutions

LIFE 4 HEAT RECOVERY

Aalborg, Denmark – Monitoring systems, passive liquid-cooling system



The demo focused on the liquid cooling part, based on a *passive two-phase thermosyphon circuit* (proprietary design of project partner Heatflow). Such cooling system has higher efficiency than air cooling: it is hence suitable for the state-of-the-art high-power CPUs/GPUs and at the same time it allows for higher recovery temperatures. A peak temperature of 59 °C was reached, though a safer limit for the current setup was identified to be 50 °C.

Heat meter

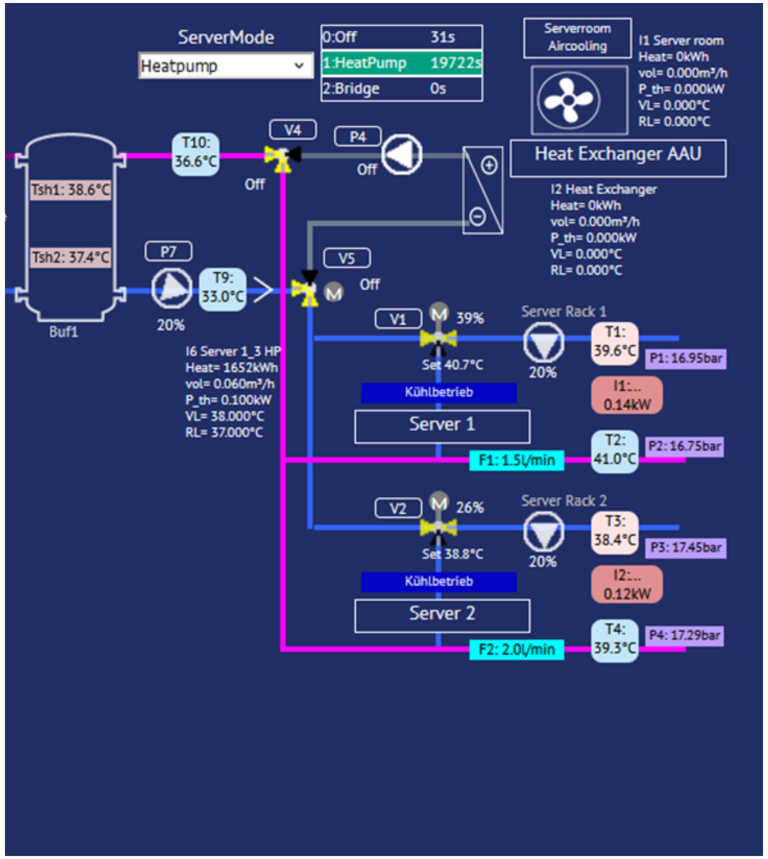
Power meter

LIFE4HeatRecovery – Waste heat recovery solutions

Aalborg, Denmark – Monitoring system

A dedicated control interface was developed for the demo.

Due to the prototype nature of this installation, this was ideal to flexibly test and adapt operating conditions.



Storage and server racks section

THE LIFE4HeatRecovery PROJECT

Focus on the demo cases: Heerlen, the Netherlands

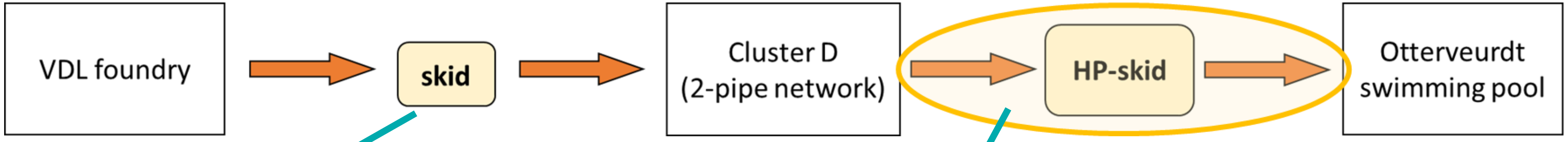
LIFE4HeatRecovery – Waste heat recovery solutions

LIFE 4 HEAT RECOVERY

Heerlen, the Netherlands – Heat recovery from the cooling system of a foundry into a **cold** network

Waste heat recovery system description: first stage

Waste heat recovery from VDL foundry (**producer**) and heat supply to Otterveurdt swimming pool (**consumer**)



This skid only consists of a heat exchanger since the foundry waste heat is available at a temperature higher than the one of the network cluster D. As the latter is a "cold" network,
the maximum allowed recovery temperature is 42 °C.

Waste Heat Recovery Substation

- monodirectional HP-skid providing **only heat** to the user.
- monodirectional connection with the network.

It could also include the waste heat available at the swimming pool from the cooling process. In the first stage of development, the HP-skid is not ready to recover it.

Local heating demand (55-65 °C)

Waste heat (25-40 °C)

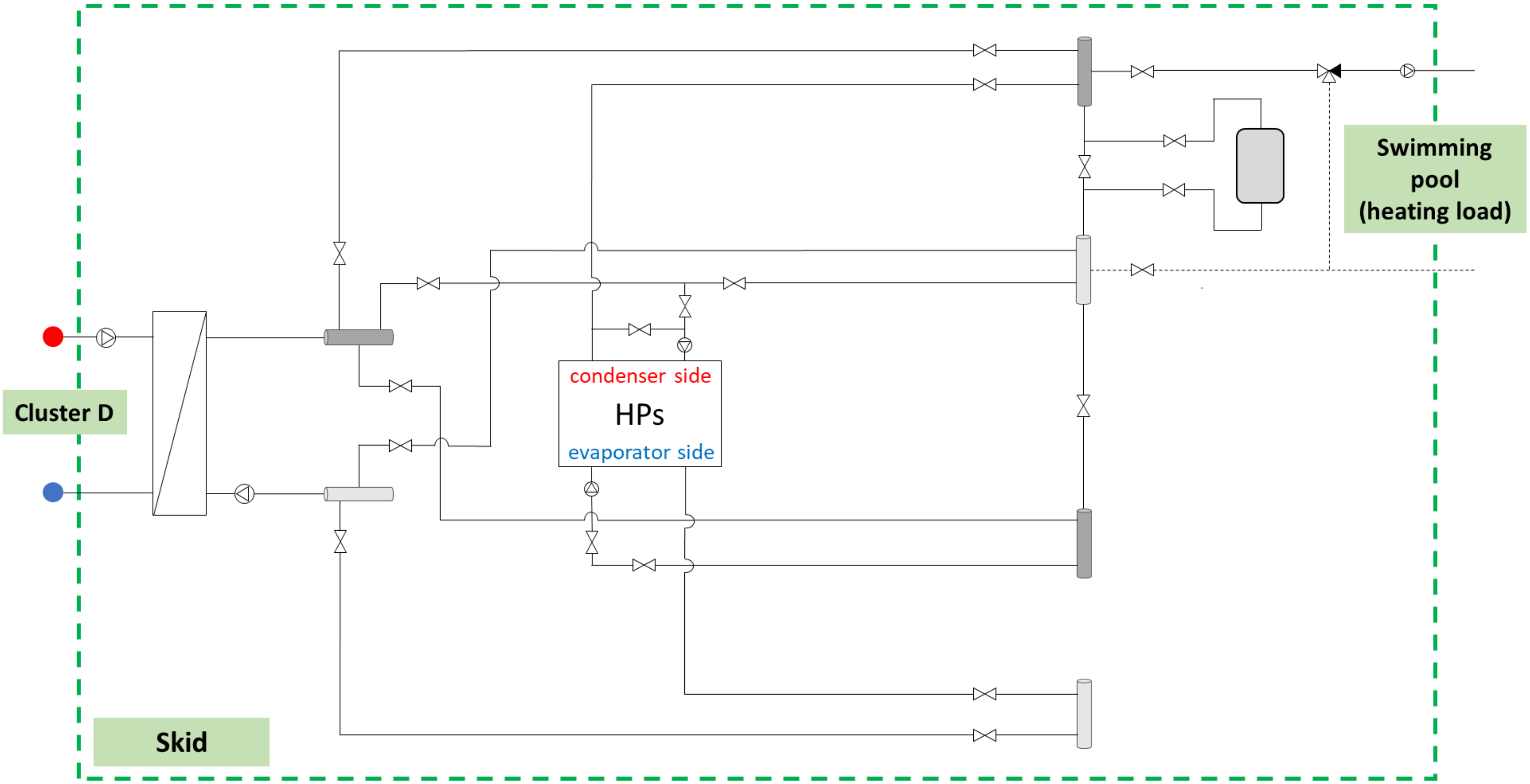
District heating (30 °C)

Heat flow

LIFE4HeatRecovery – Waste heat recovery solutions

LIFE 4 HEAT RECOVERY

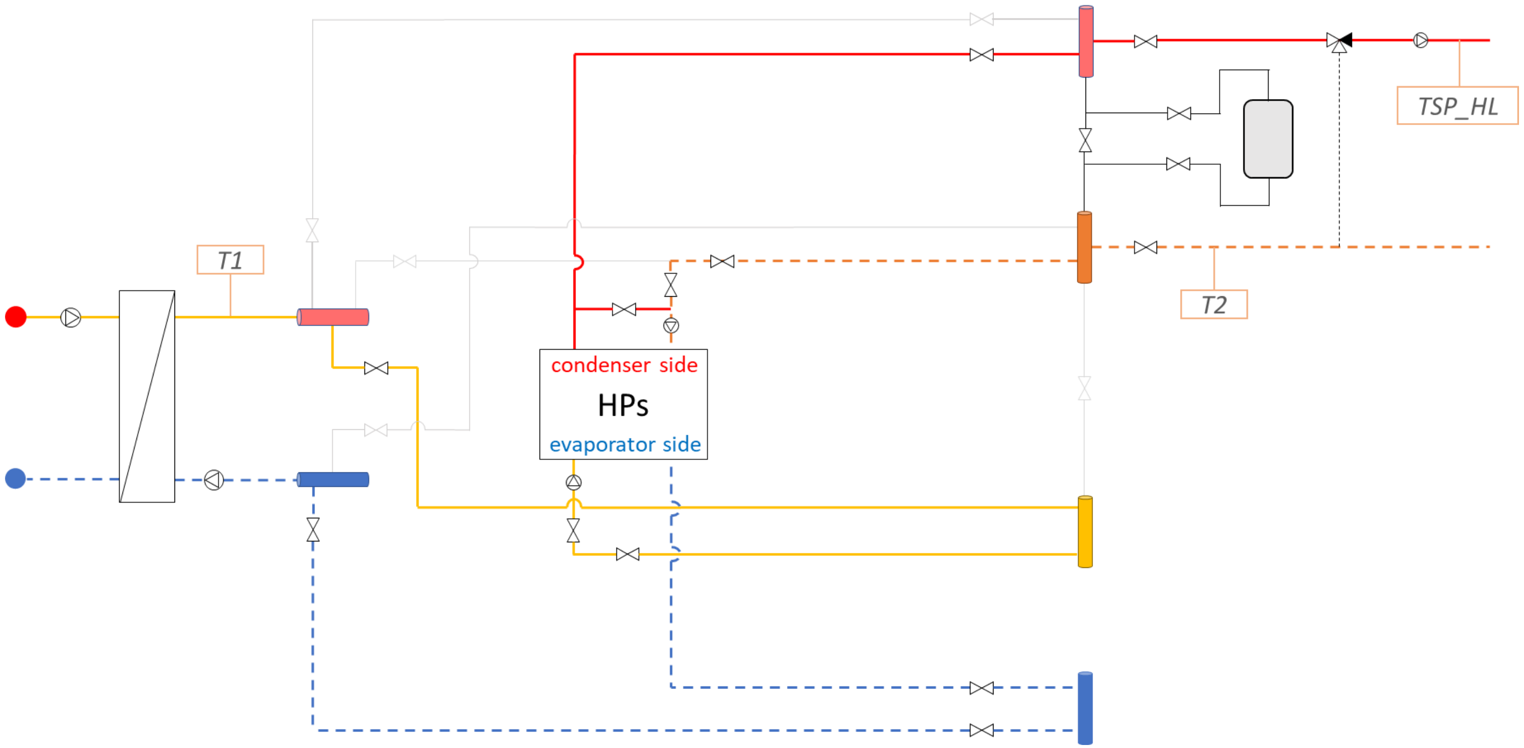
Heerlen, the Netherlands – Substation configuration: first stage



- The skid draws heat from the network and supplies it to the user at the desired temperature level.
- Monodirectional connection between the skid and the network.
- One or more heat pumps connected in series or parallel can be installed depending on requirements.
- The heat exchanger enables hydraulic separation between the skid and the network.
- This configuration allows for different operating schemes to optimise skid performance according to network and user thermal levels (see next).

LIFE4HeatRecovery – Waste heat recovery solutions

Heerlen, the Netherlands – Operating scheme: hydraulic separation



Thermal level combination

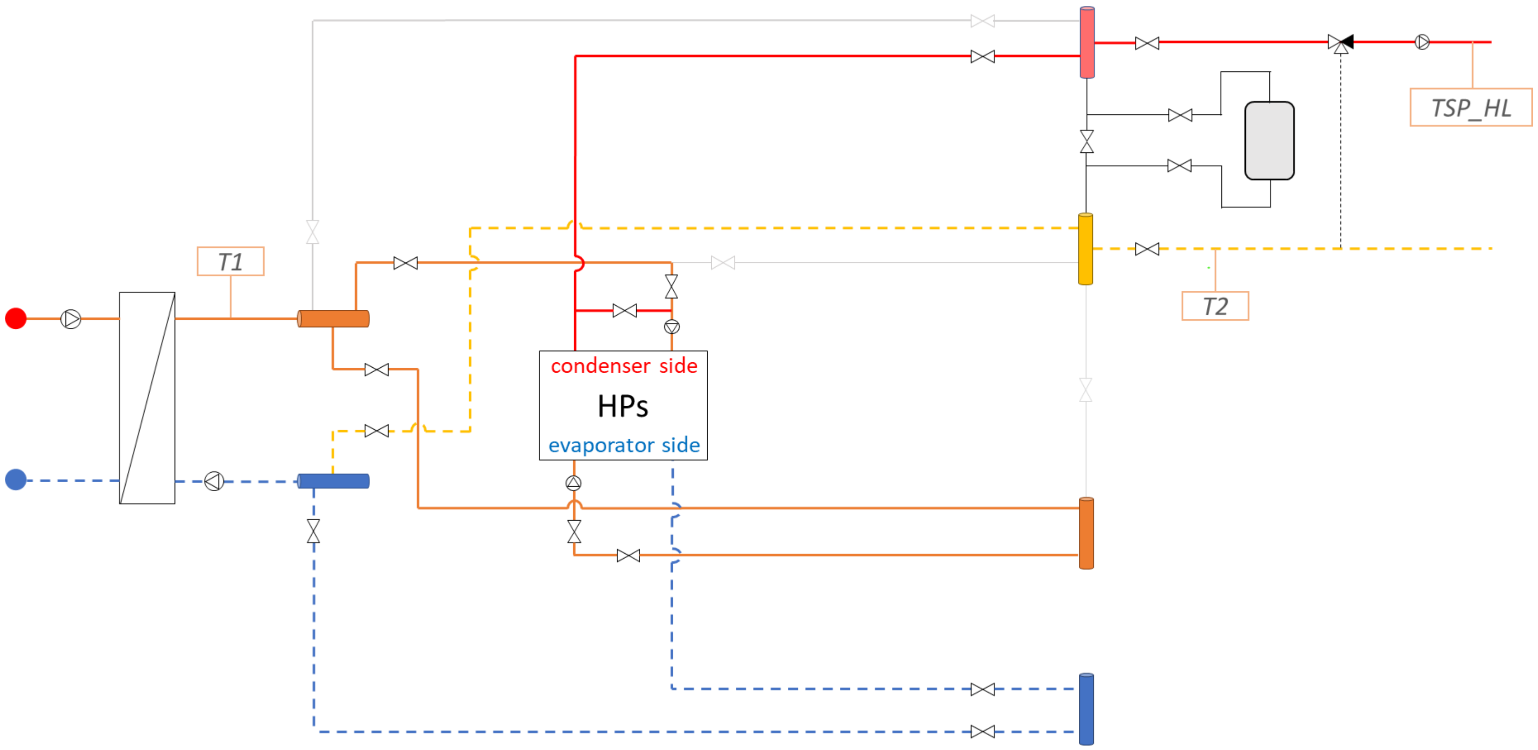
$$\mathbf{TSP_{HL} > T_2 > T_1}$$

Passive sharing: 0 %

Heat pumps operation is required since T_1 does not meet the level required by the user TSP_{HL}.
The flow coming from the HEX is sent to the evaporator side of the heat pumps while the return water from the user goes to the condenser side.
HPs allow for hydraulic separation between HEX and user.

LIFE4HeatRecovery – Waste heat recovery solutions

Heerlen, the Netherlands – Operating scheme: split flow



Thermal level combination

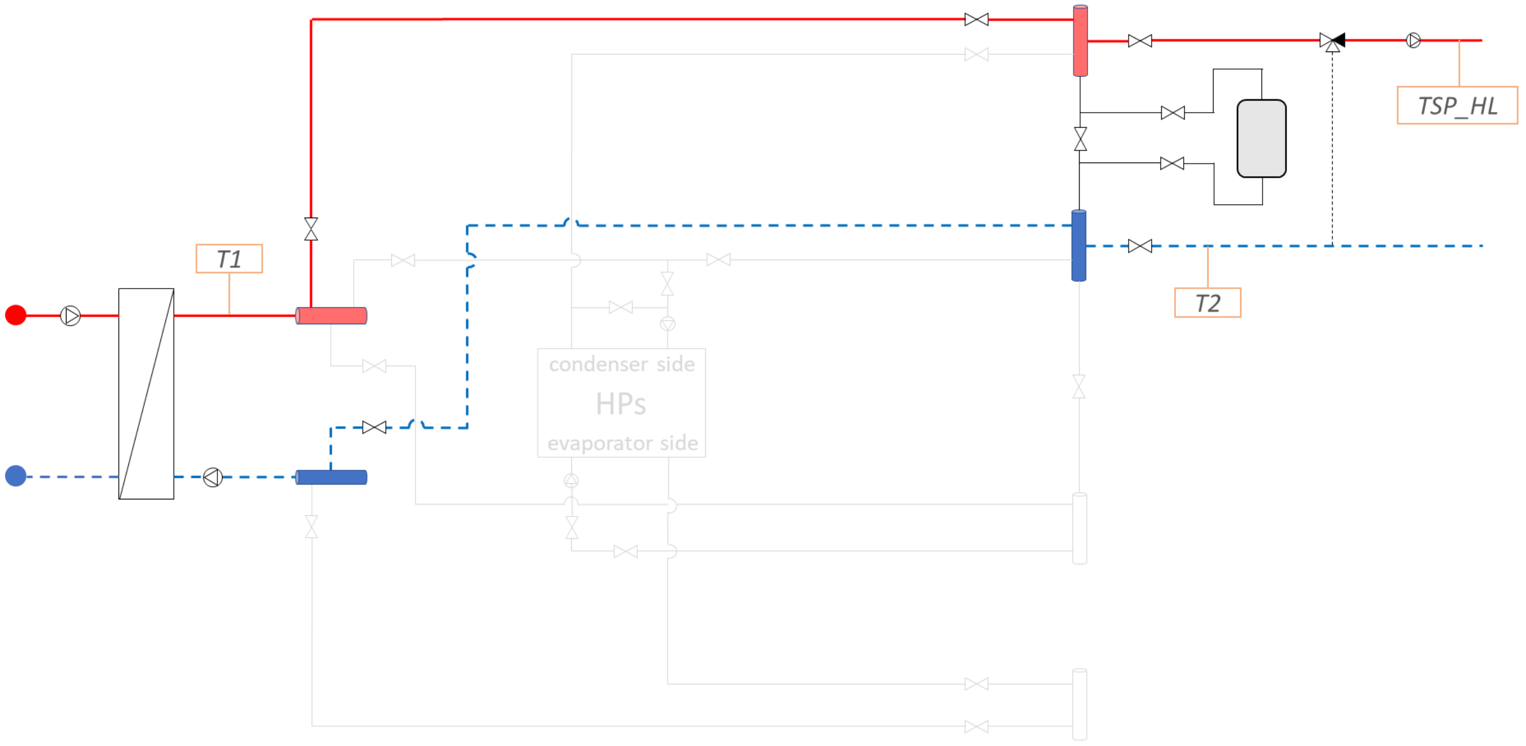
$$\mathbf{TSP_{HL} > T_1 > T_2}$$

Theoretical passive sharing: $\frac{T_1 - T_2}{TSP_{HL} - T_2}$

Heat pumps operation is required since T_1 does not meet the level required by the user TSP_{HL}.
The flow coming from the HEX is sent to both the evaporator and condenser side of the heat pumps. The return water from the user directly goes to the HEX.
Multiple HP modules manage temperature differences.

LIFE4HeatRecovery – Waste heat recovery solutions

Heerlen, the Netherlands – Operating scheme: heat pump bypass



Thermal level combination

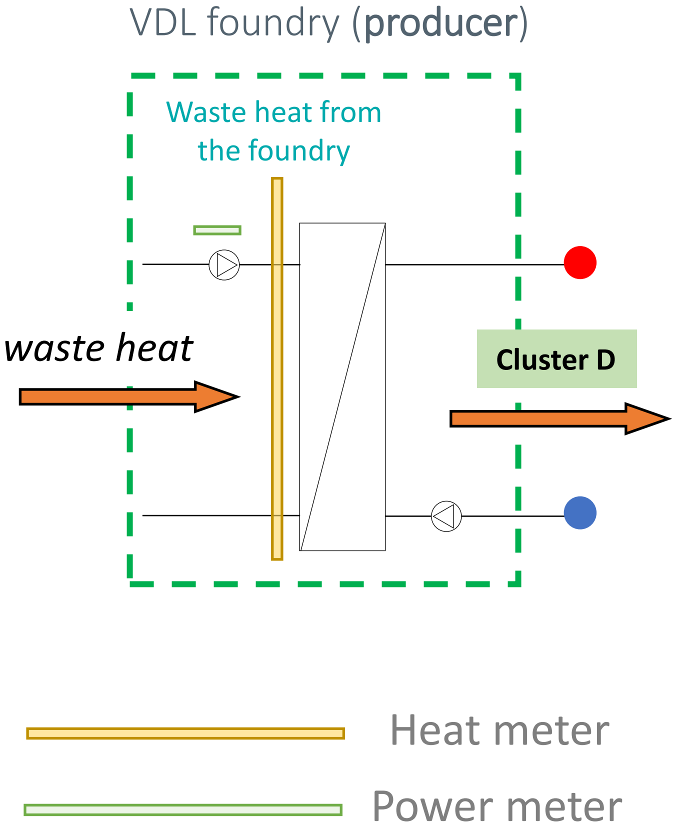
$$T_1 > TSP_{HL}$$

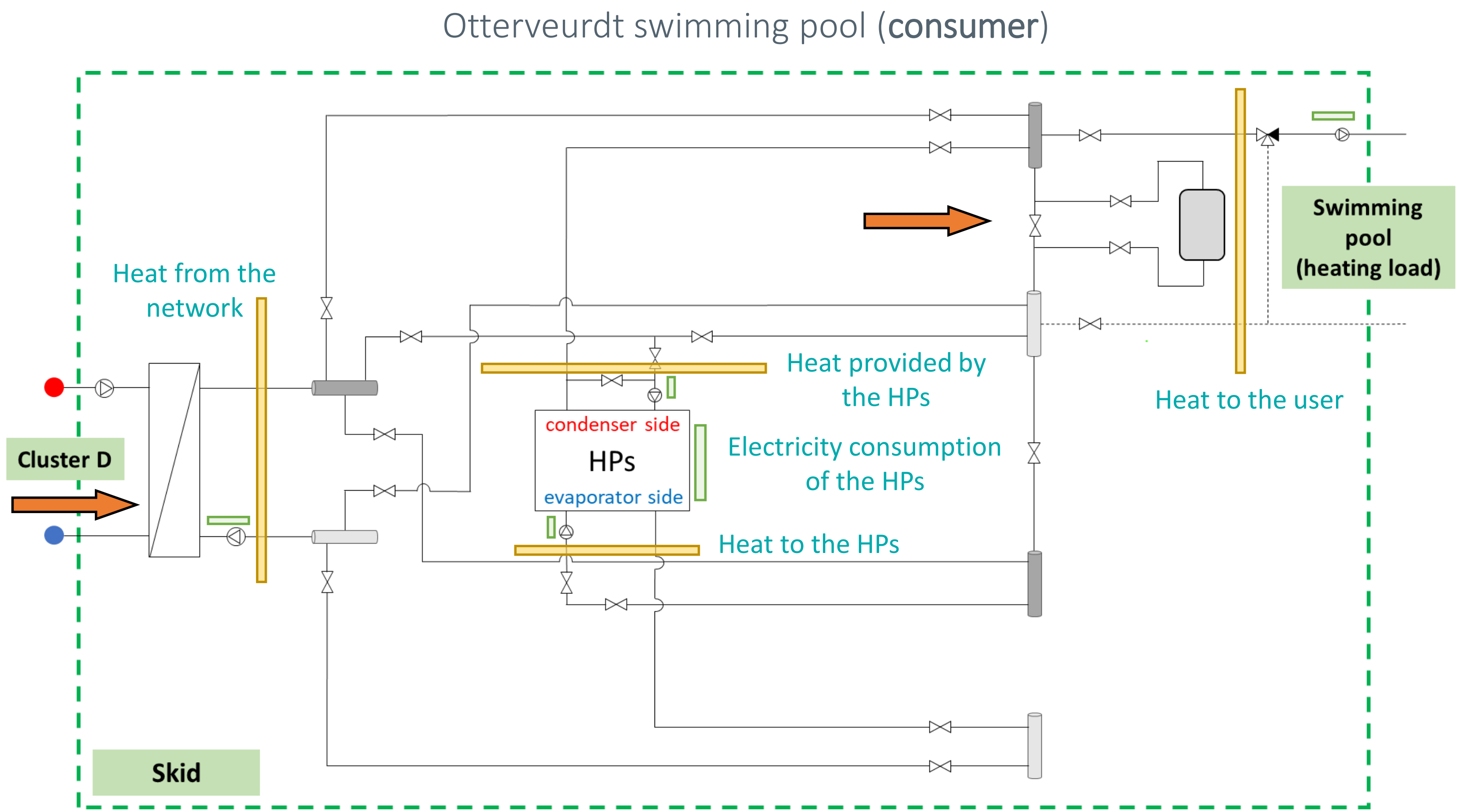
Passive sharing: 100 %

Since the temperature T_1 of the hot water leaving the heat exchanger is higher than the temperature TSP_{HL} required by the user, the heat pumps can be bypassed. The flow coming from the HEX is directly supplied to the user.

LIFE4HeatRecovery – Waste heat recovery solutions

Heerlen, the Netherlands – Monitoring system



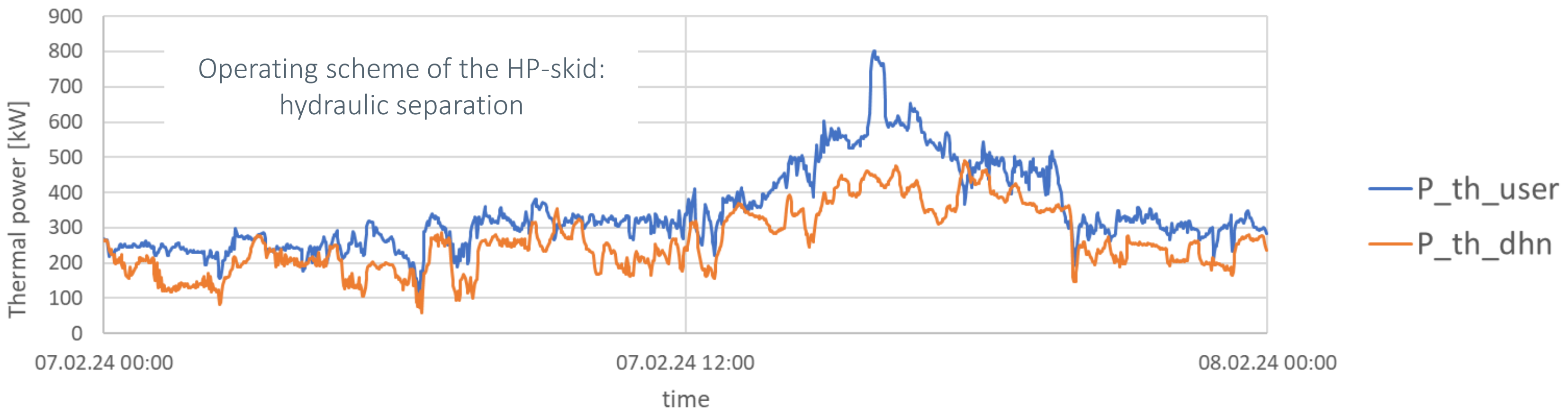


LIFE4HeatRecovery – Waste heat recovery solutions

Heerlen, the Netherlands – Monitoring results

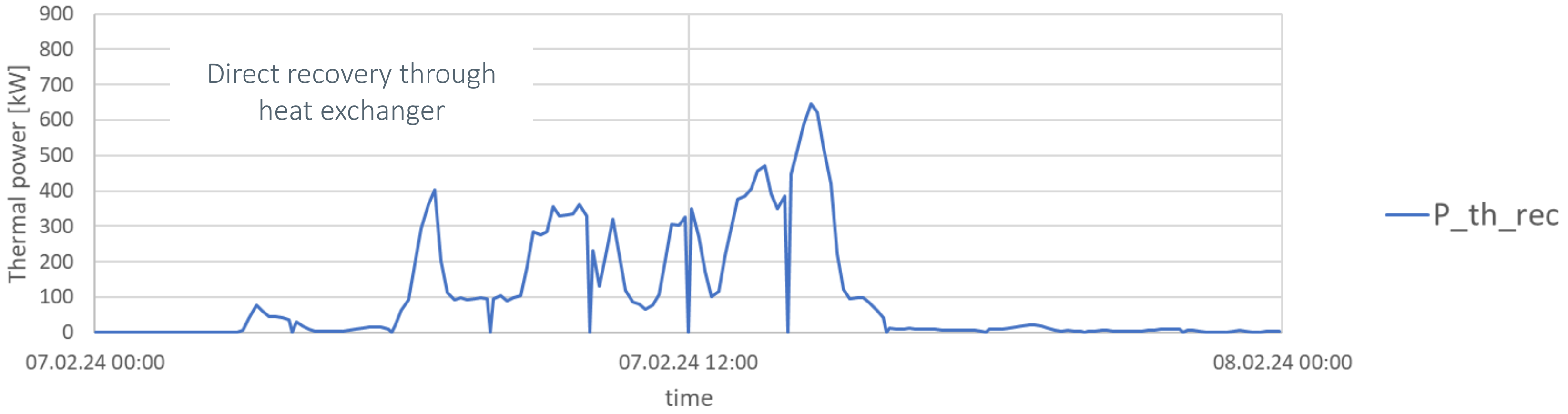
SWIMMING POOL (consumer)

Heat drawn: **6.3 MWh**
Heat supplied: **8.3 MWh**
Electricity: 2.1 MWh
COP: 4



FOUNDRY (producer)

Heat recovered: **2.5 MWh**
Electricity: 22 kWh



LIFE 4 HEAT RECOVERY

LIFE4HeatRecovery – Waste heat recovery solutions

Heerlen, the Netherlands – Monitoring results

FEBRUARY 2024

Swimming Pool (consumer) – Heat Pump skid	
Heat supplied to the user	206 MWh
Heat drawn from the network	157 MWh
Total electricity consumption	54 MWh
COP of the skid	**3.8**
Operating scheme	Hydraulic separation

Foundry (producer) – Heat Exchanger skid	
Heat recovered in the network	54 MWh (35 % of the heat drawn by the consumer)
Electricity consumption for pumping	0.31 MWh

MARCH 2024

Swimming Pool (consumer) – Heat Pump skid	
Heat supplied to the user	198 MWh
Heat drawn from the network	150 MWh
Total electricity consumption	55 MWh
COP of the skid	**3.6**
Operating scheme	Hydraulic separation

Foundry (producer) – Heat Exchanger skid	
Heat recovered in the network	63 MWh (42 % of the heat drawn by the consumer)
Electricity consumption for pumping	0.42 MWh

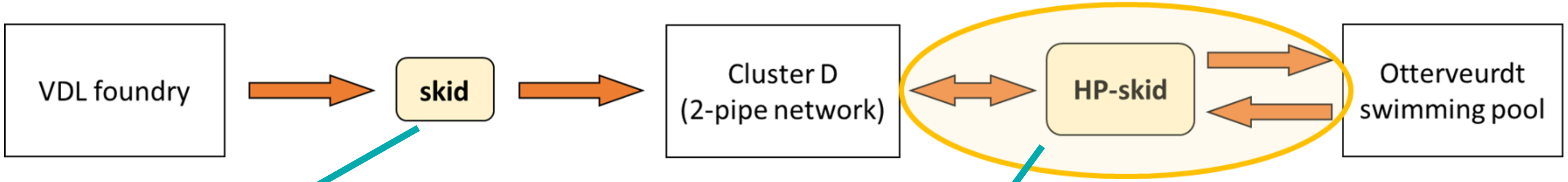
LIFE4HeatRecovery – Waste heat recovery solutions

LIFE 4 HEAT RECOVERY

Heerlen, the Netherlands – Heat recovery from the cooling system of a foundry into a cold network

Waste heat recovery system description: <u>second stage (possible future expansion)</u>

Waste heat recovery from VDL foundry (**producer**) and heat and cold supply to Otterveurdt swimming pool (**prosumer**)



This skid only consists of a heat exchanger since the foundry waste heat is available at a temperature higher than the one of the network cluster D. As the latter is a "cold" network,
the maximum allowed recovery temperature is 42 °C.

Waste Heat Recovery Substation

- bidirectional HP-skid providing **both heat and cold** at the same time to the user.
- bidirectional connection with the network.

It also includes the waste heat available at the swimming pool from the cooling process.

Local heating demand (55-65 °C)

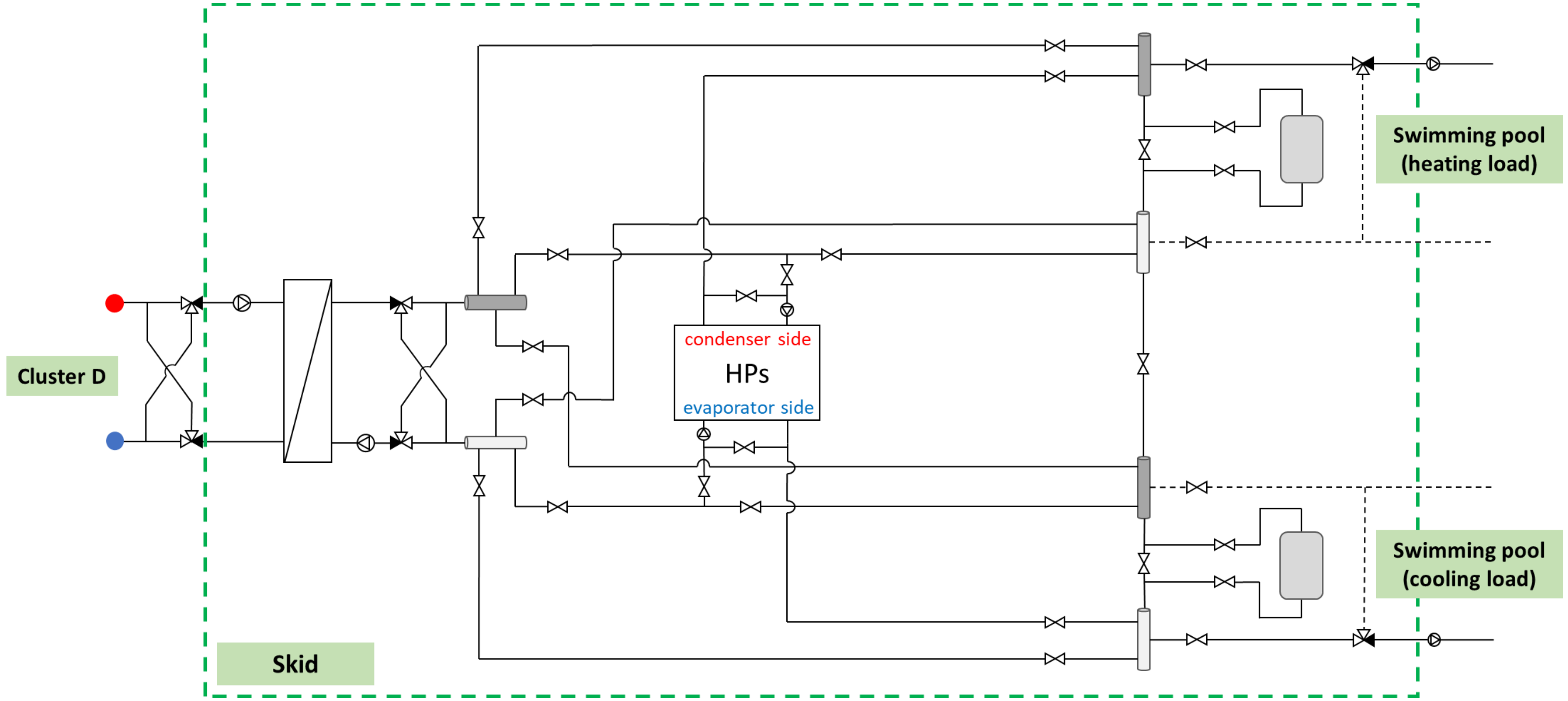
Waste heat (25-40 °C)

District heating (30 °C)

Heat flow

LIFE4HeatRecovery – Waste heat recovery solutions

Heerlen, the Netherlands – Substation configuration: second stage

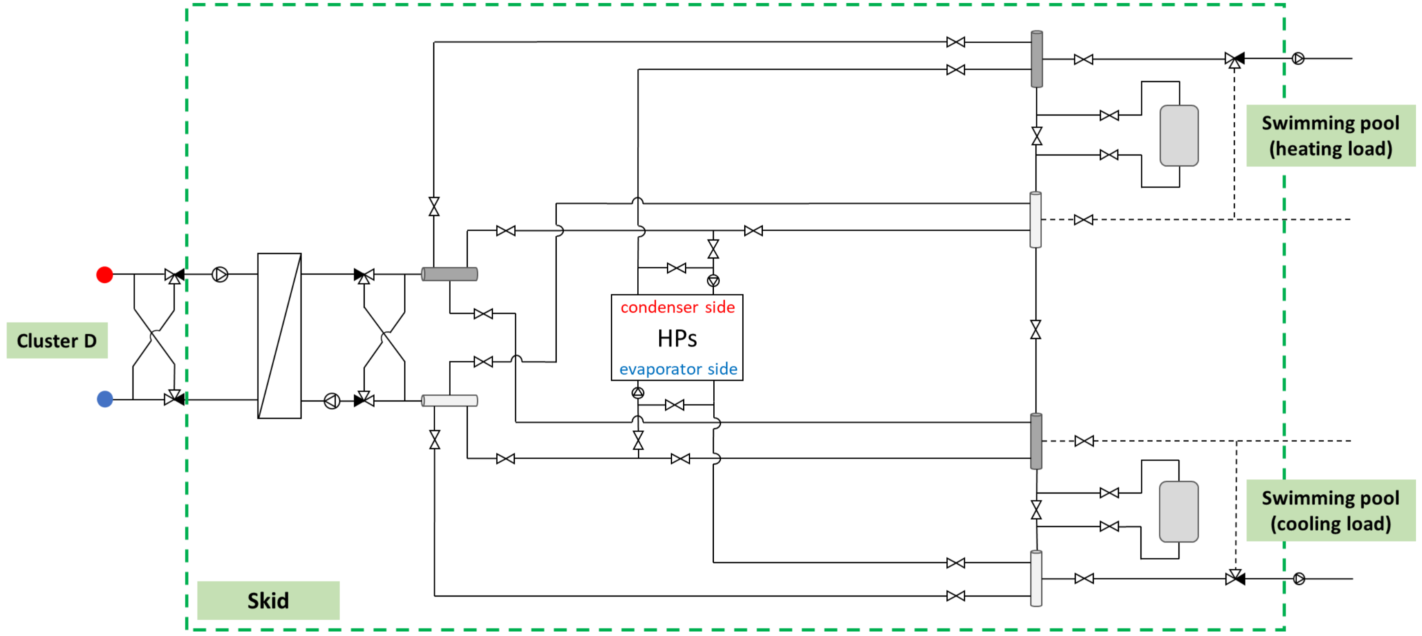


- Now the skid can supply both heat and cold to the user at the same time.
- The shortage of heat/cold is drawn from the network thanks to a bidirectional connection made by two pairs of 3-way valves.
- One or more heat pumps connected in series or parallel can be installed depending on requirements.
- The heat exchanger enables hydraulic separation between the skid and the network.
- To optimize the performance, different operating schemes, decided according thermal levels of the user and the network, are enabled by the complex hydraulic configuration.

LIFE4HeatRecovery – Waste heat recovery solutions

Heerlen, the Netherlands – Substation configuration: second stage

Strengths and weaknesses of the substation



- **Strengths**
  - ✓ **Modularity.** Using multiple HP modules, a larger flexibility in the sizing is introduced.
  - ✓ **Replicability.** Easy adaptation to different combinations of thermal levels.
  - ✓ **Bivalent.** Avoiding the installation of two dedicated heat pump modules for heating and cooling load, respectively.
- **Weaknesses**
  - ✓ **Complex hydraulics.** Many hydraulic components (valves, actuators, piping) are present. (∗)
  - ✓ **Complex control.** Switching between the different operating schemes requires a smart control unit with transition hysteresis to avoid instabilities.

(∗) In less complex situations, as in the first stage, it is possible not to install all the hydraulic components, deriving simpler configurations by installing only the necessary parts.

THE LIFE4HeatRecovery PROJECT

Dynamic simulations

Why perform simulations?

Conducting simulations on energy systems, such as district heating networks and substations, is relevant for several reasons:

- **Planning and design:** during the design phase, simulations enable testing of different configurations and scenarios, helping to choose optimal solutions before actual installation.
- **Impact assessment:** simulations allow for the evaluation of the impact of new solutions/scenarios on existing systems. For example, the integration of a heat source, of a storage, or a new group of users into an existing district heating.
- **Performance analysis:** they allow for the preliminary estimation of system performance under various operating conditions and scenarios, leading to a better understanding of the system's capabilities and limitations.
- **Efficiency optimization:** simulations help identify the most efficient ways to operate, manage and control energy systems, reducing losses and improving overall efficiency.
- **Risk management**: simulations can predict and analyze potential failures and issues, aiding in the development of mitigation strategies and emergency plans.
- **Economic evaluation**: they enable the assessment of the economic aspects, such as cost-effectiveness, return on investment, and overall financial impact of different scenarios and technologies.

Why perform simulations?

LIFE 4 HEAT RECOVERY

Impacts of a waste heat sources integration

Local impacts (i.e., on the user)

- Is the waste heat recovery skid **able to meet the local needs** in terms of supply temperatures and thermal powers?
- In case of local reutilization of the heat recovered, are the technical and environmental **performance** of the skid better than the ones of other alternative solutions (e.g., individual gas boiler or heat pump)?

Global impacts (i.e., on the district heating)

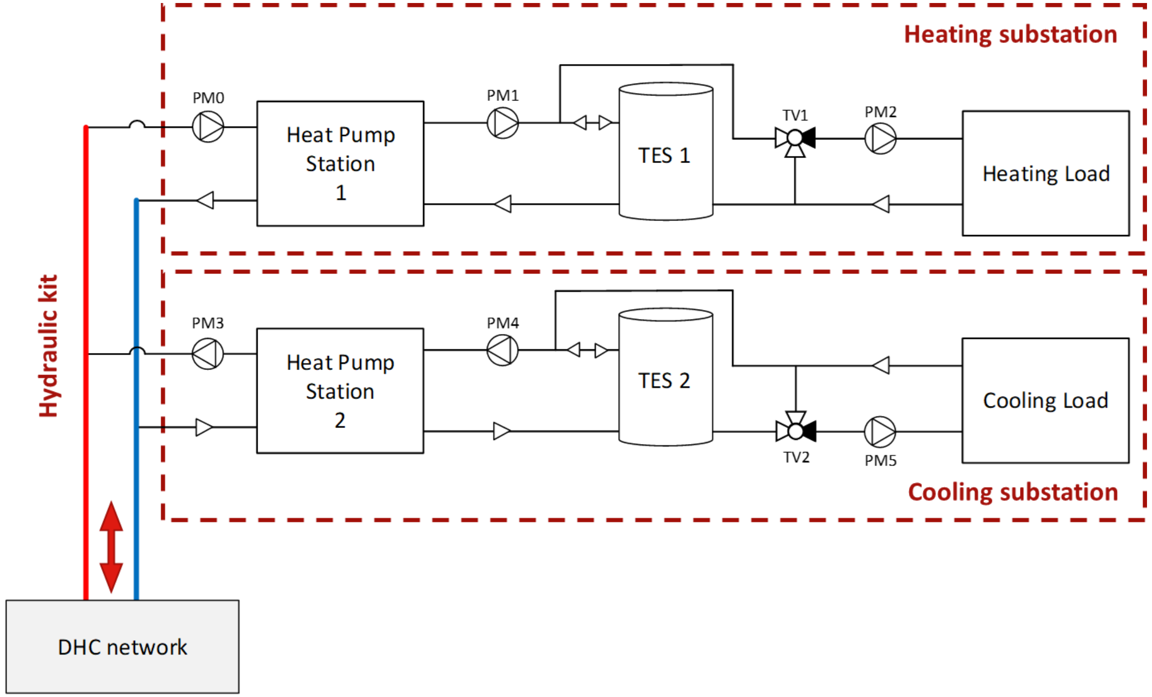
- What is the contribution of integrating waste heat sources to the **decarbonization of the district heating**?
- What are the **temperatures and flow rates** exchanged between the skid and the network?
- Does the integration of the waste heat source cause **hydraulic issues in the network**?

Simulation models

Modelling of low-temperature waste heat recovery substation

LIFE 4 HEAT RECOVERY

- Within the LIFE4HeatRecovery project, it was necessary to conduct substation simulations for all the three demo cases in order to assess both the overall system performance and the impact of their integration in the district heating.
- The used approach involved the design of a low-temperature waste heat recovery substation **sufficiently flexible to replicate all three demonstration cases** and similar applications, thus avoiding the development of specific models for each case.
- This is made possible by the implementation of a **smart hydraulic design** within the heat pump station, which enables different operating schemes (including the bypass of the heat pump in case this is not foreseen in the actual installation).
- In the model, the substation is implemented considering a complex and complete configuration, with two thermal energy storages and heat pumps, a smart hydraulic design inside the heat pump stations, and with several modulating pumps. Despite this complexity, acting on different parameters of the model it is also possible to simulate simpler waste heat recovery substations.



LIFE 4 HEAT RECOVERY

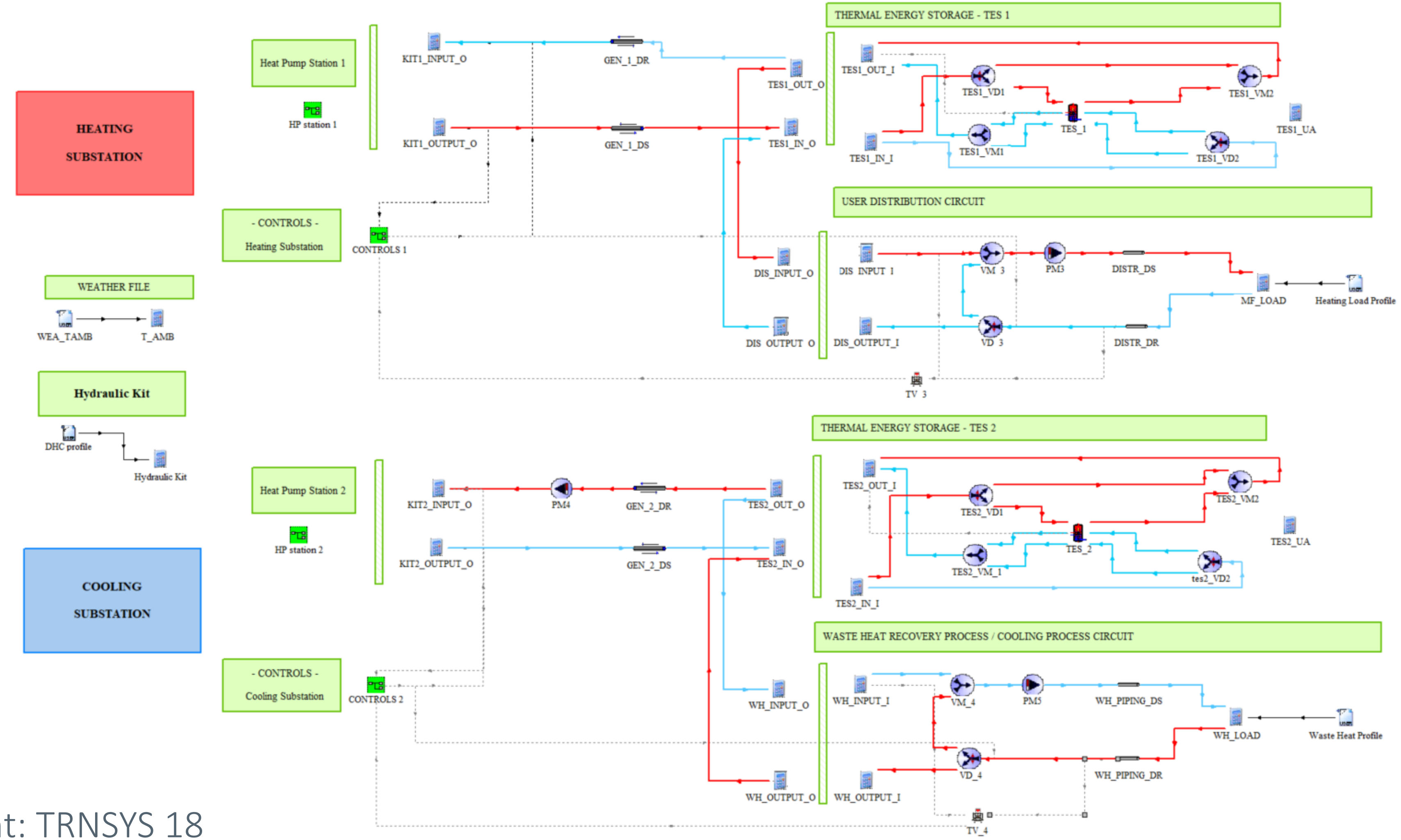
DYNAMIC SIMULATIONS

Substations

Detailed model of low-temperature waste heat recovery substation

LIFE 4 HEAT RECOVERY

Heat exchange with the network



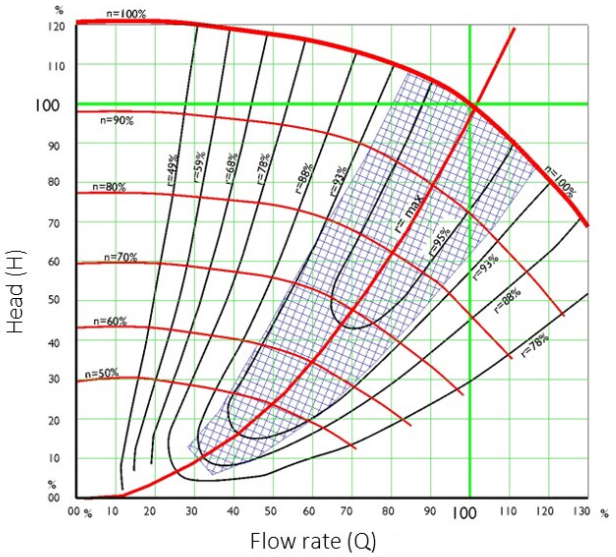
Heating load

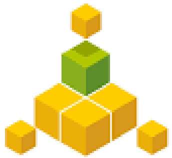
Waste heat from a cooling load

Software environment: TRNSYS 18

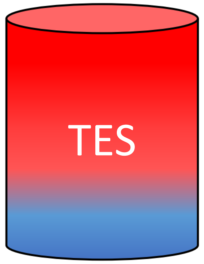
Detailed model of low-temperature waste heat recovery substation

- **Electrical consumption** of the circulation pumps





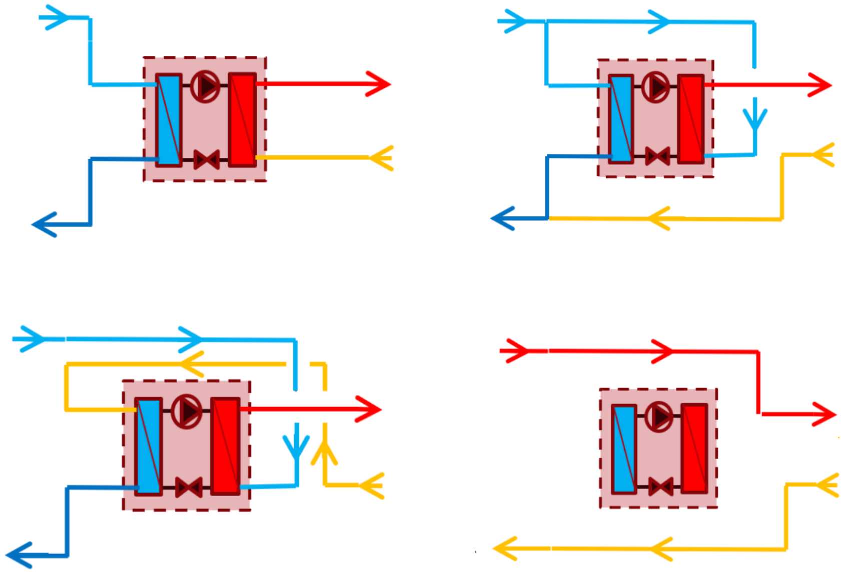
- Both **one-sensor and two-sensor control logics** are implemented for the storages



- **Thermal losses** of the storages and the piping

- **Performance map** of the heat pump calibrated on real data.

- Different **operating schemes** of the heat pump station (including the heat pump bypass).



Software environment: TRNSYS 18

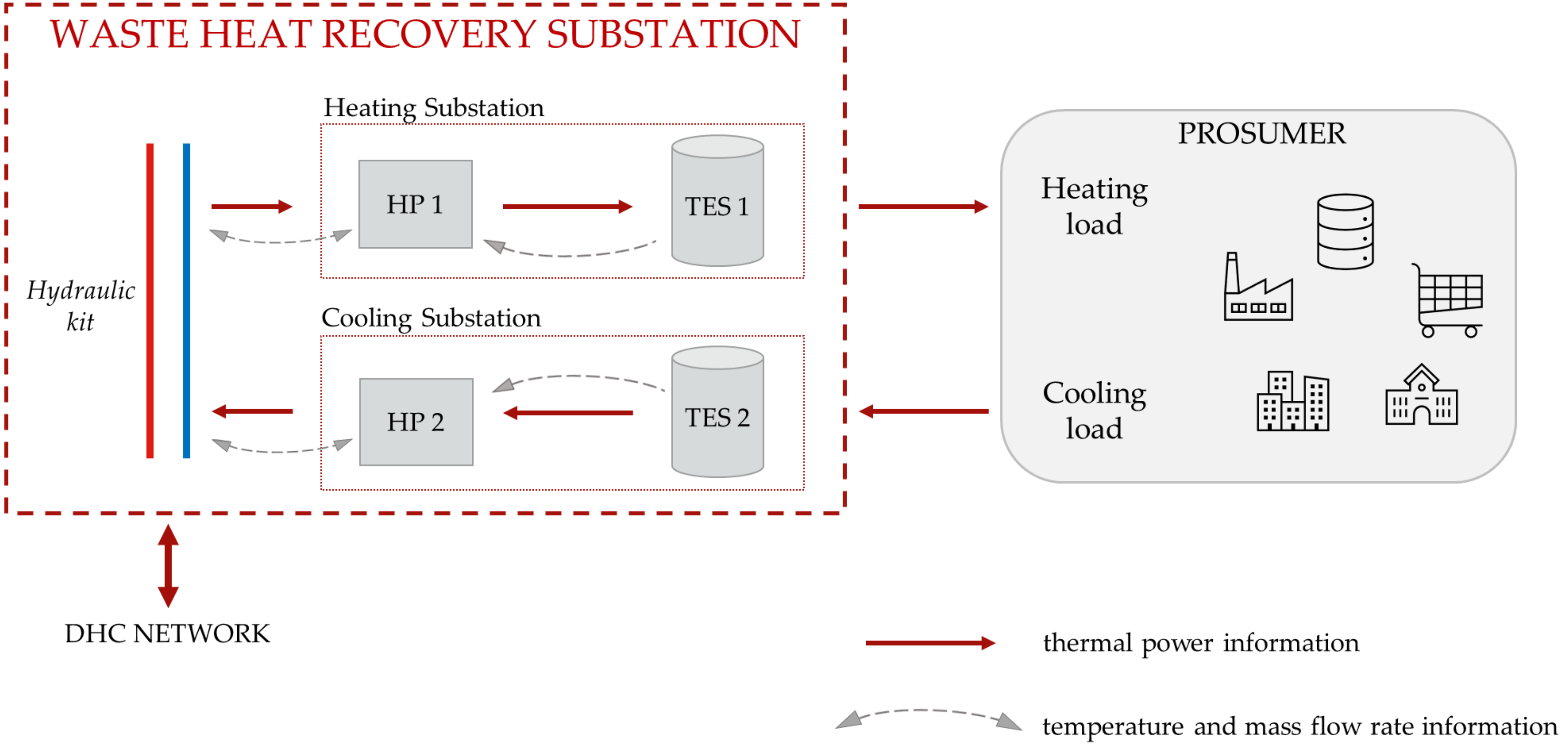
Detailed model of low-temperature waste heat recovery substation

LIFE 4 HEAT RECOVERY

Software environment: TRNSYS 18

Main inputs	Main outputs	Strengths and weaknesses
• Ambient temperature • Temperature of the network • Thermal power and temperature level of the waste heat • Thermal power and temperature level of the local heating demand • Technical information and performance data of the heat pumps • Geometry and insulation features of the storages and pipes • Perfomance curve of the circulating pumps • Control logics of the system	• Heat fluxes • Electricity consumption of the heat pumps • Electricity consumption of the pumps • Thermal losses • Flow rates and temperature exchanged between the network and the skid, and between the user and the skid • COP of the heat pump • COP of the system	Strengths: • Useful to estimate the impact of the integration of waste heat recovery substation into the network • Useful to estimate the ability of the substation to meet the needs of the user • Can be used to conduct sizing analysis of each components Weaknesses: • High computational effort • The knowledge of several detailed information is required

Reduced-Order Model (ROM) of low-temperature waste heat recovery substation

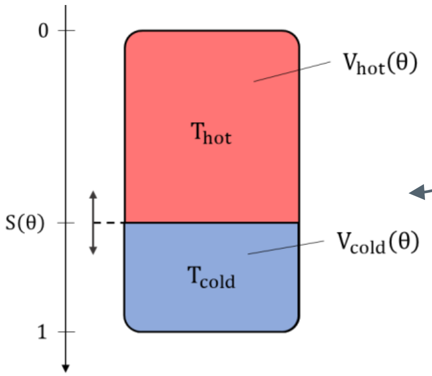


Software environment: python

Reduced-Order Model (ROM) of low-temperature waste heat recovery substation

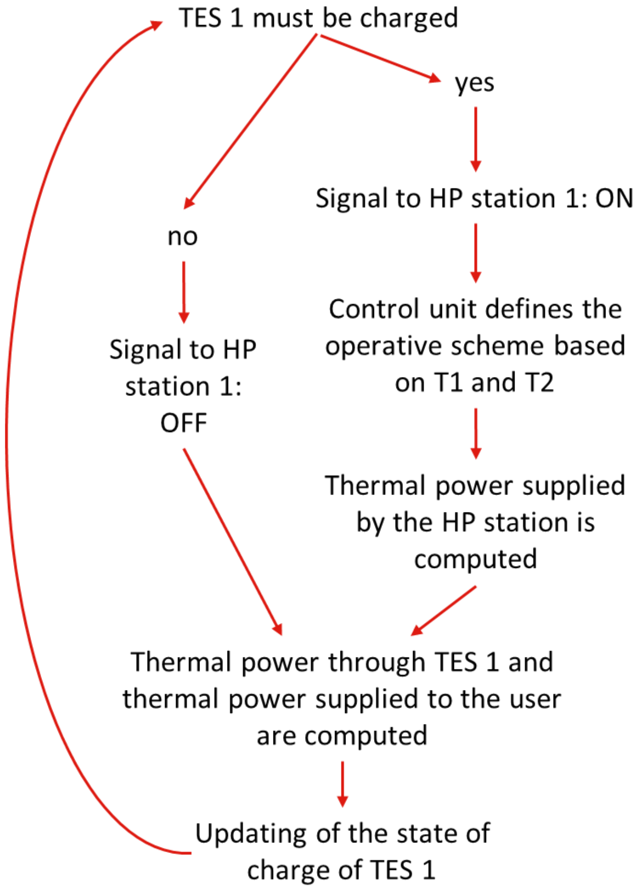
LIFE 4 HEAT RECOVERY

- All the hydraulic connections (i.e., pipes and valves) are removed.
- The heat pumps and the storages are implemented as isolated systems, exchanging temperature and thermal power information.
- The storages are modelled using a simplified approach which involves two separate volumes of hot and cold water, with an ideal thermocline of zero thickness as the separating surface. A calibration of the return temperature to the heat pump is needed.



Software environment: python

Example of control logic:



Reduced-Order Model (ROM) of low-temperature waste heat recovery substation

Software environment: python

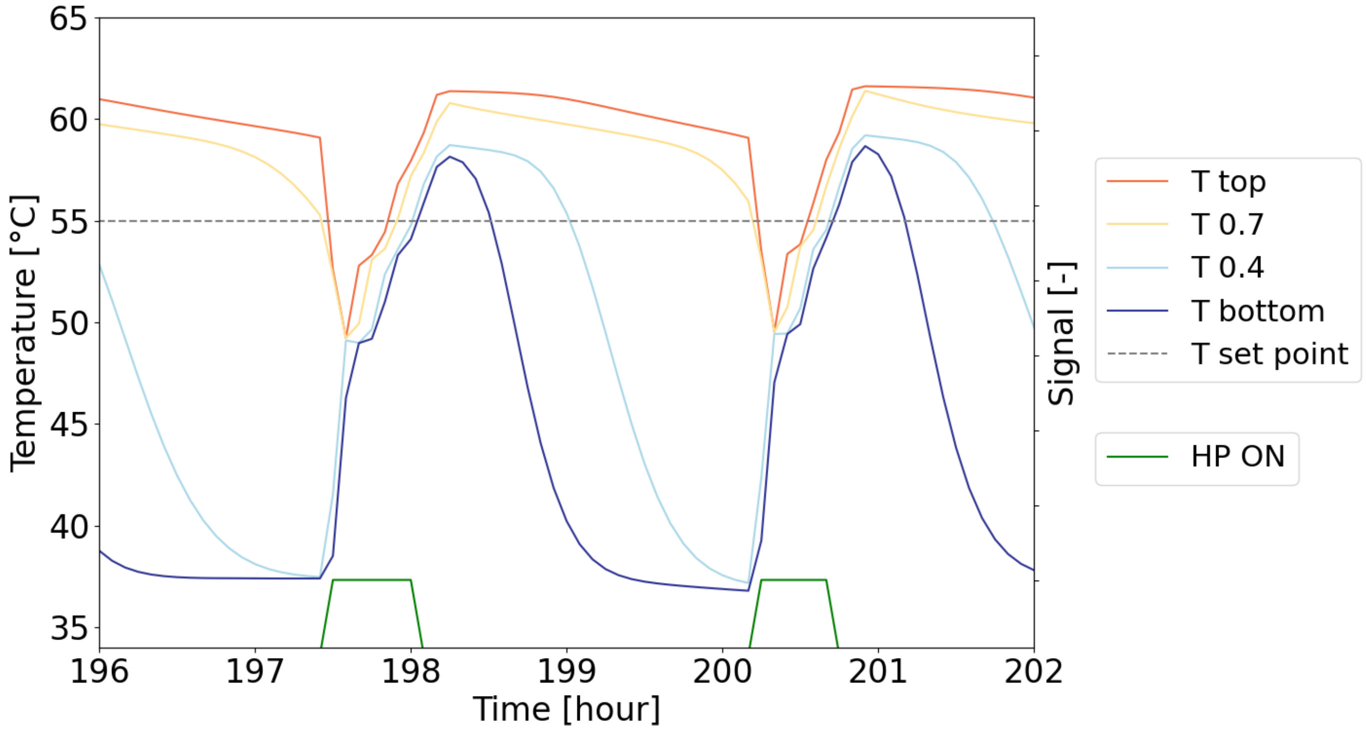
Main inputs	Main outputs	Strengths and weaknesses
• Ambient temperature • Temperature of the network • Thermal power and temperature level of the waste heat • Thermal power and temperature level of the local heating demand • Technical information and performance data of the heat pumps • Control logics of the system	• Heat fluxes • Electricity consumption of the heat pumps • COP of the heat pump • COP of the system	Strengths: • Lower computational effort • Useful to optimize the control logics of the systems • Less technical information is required • Can be integrated into larger models capable of simulating entire district heating networks Weaknesses: • A calibration is required • Less accuracy

LIFE 4 HEAT RECOVERY

Simulation results – Detailed model

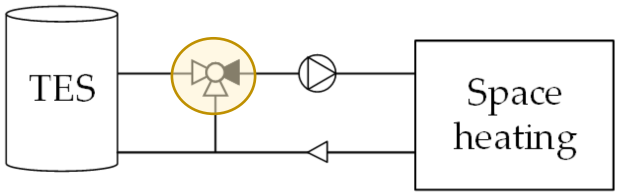
- The **thermal stratification in the storage** ensures a sufficiently high and approximately constant supply temperature to the user during the period when the heat pump is off.

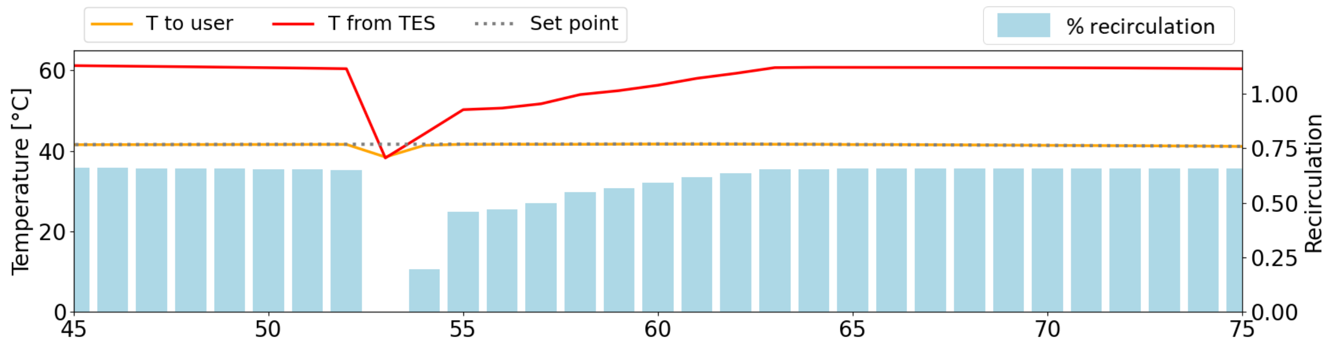
- The stratification is almost completely lost during heat pump operation due to high **mixing phenomena**.



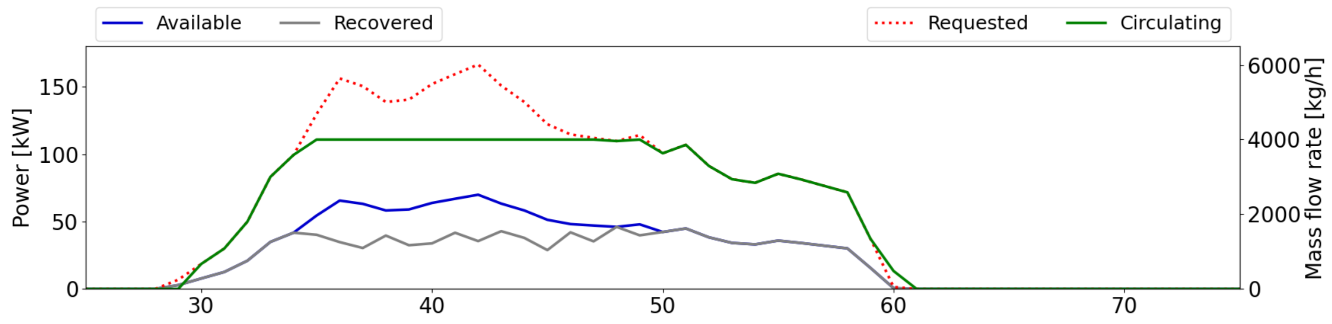
Simulation results – Detailed model

Thanks to the **thermostatic valve**, the supply temperature to the user is regulated by recirculation of the return water.

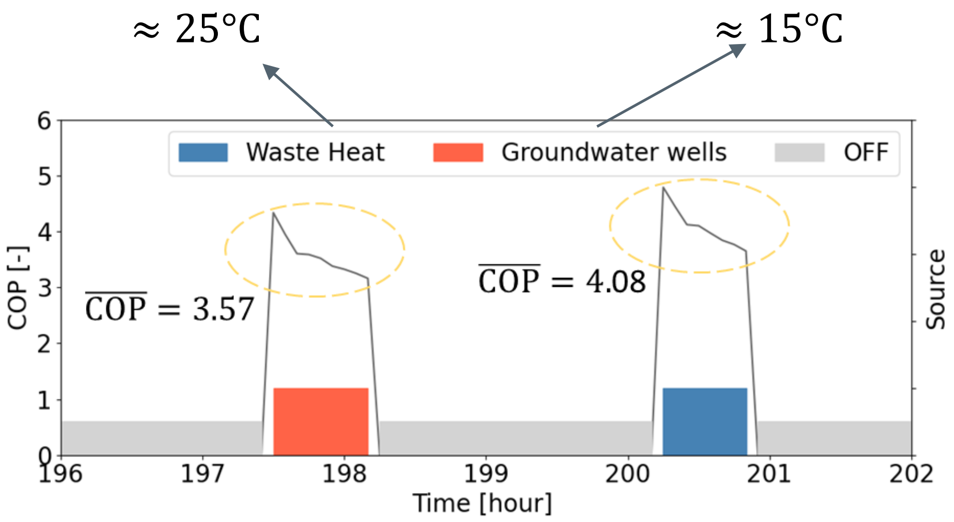


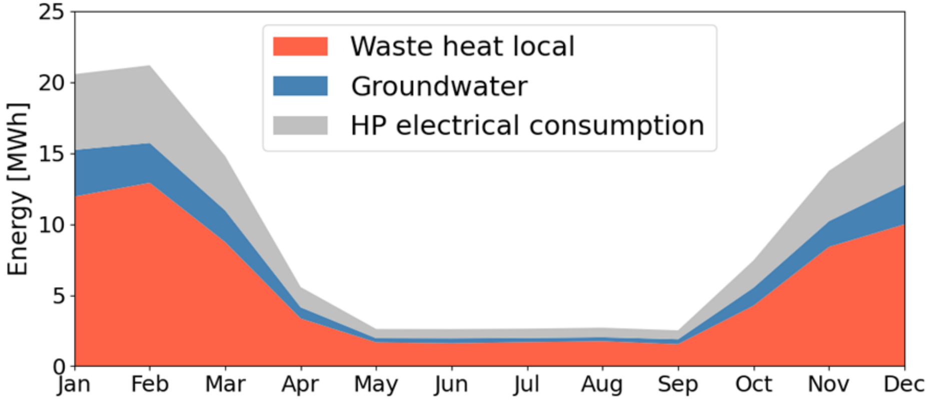


The detailed model also makes it possible to **highlight undersizing of the circulation pumps**.
The graph shows an example where the circulation pump of the heat recovery circuit is undersized, so only part of the available heat is recovered.



Simulation results – Ospitaletto demo case





Waste heat recovery substation

$$SCOP = \frac{E_{th,CO}}{E_{el,HP}} = \mathbf{3.88} \qquad SPF = \frac{E_{th,user}}{E_{el,tot}} = \mathbf{3.59}$$

Reference system

Condensing boiler fired by natural gas, efficiency of 95%

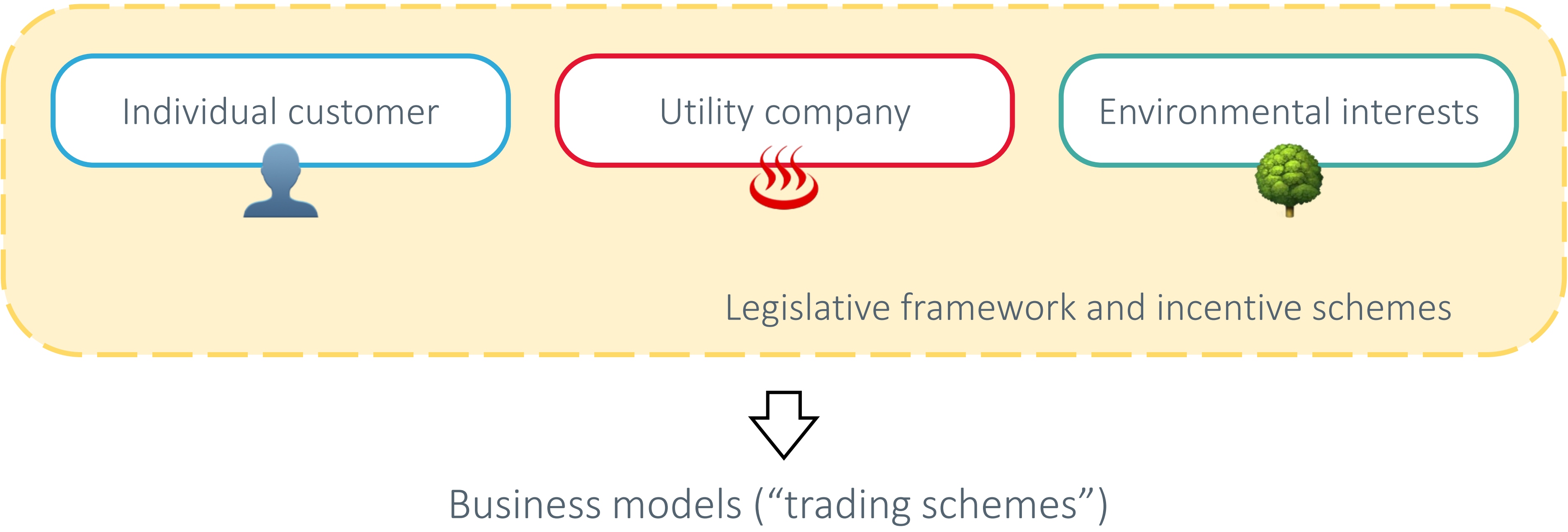
About 70% savings in non-renewable primary energy consumption and greenhouse gas emissions

THE LIFE4HeatRecovery PROJECT
Trading schemes and business models

Contribution to the project

LIFE 4 HEAT RECOVERY

Explore the potential of using waste heat recovery measures at low- and high temperature thermal network.

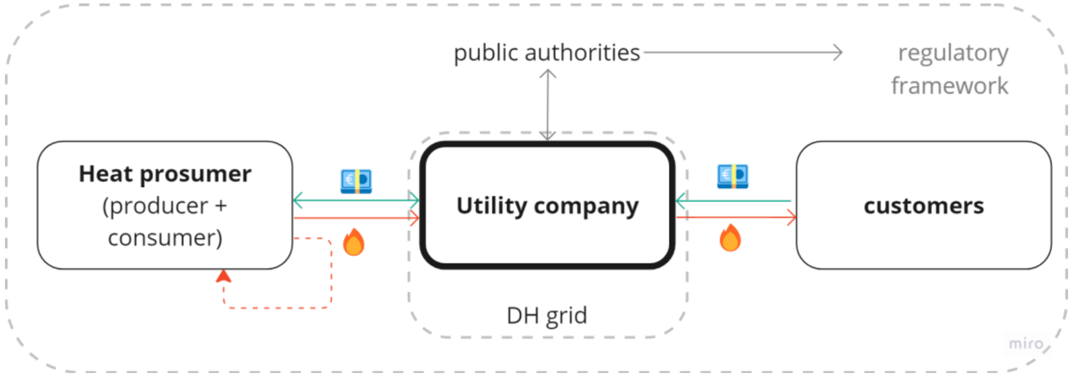


Business model

def. *A business model describes the rationale of how an organization creates, delivers, and captures value.*

how a company intends to make money
through the 4 main areas of business:

CUSTOMERS + OFFER + INFRASTRUCTURE + FINANCIAL VIABILITY



Business model canvas

LIFE 4 HEAT RECOVERY

KEY PARTNERSHIP AND RESOURCES

Local authorities
Growing decision-making autonomy and responsibility for municipalities regarding strategic decisions on energy matters. Collaboration is fundamental to guarantee financial support, approval, concession for the use of public land, and user connection.

National regulatory bodies
Collaboration with national regulators is crucial for ensuring compliance with energy and environmental regulations, facilitating the regulatory process, and promoting user protection and sustainability.

Electricity and gas network operators

Suppliers, contractors, specialized installers

Heat producer/prosumer

Investors:
- DH company
- Heat producer/prosumer
- Local authorities
- Subsidized loans
- Government funds

VALUE PROPOSTITION

Environmental sustainability

Energy efficiency

Cost competitiveness

Incentive for local economic growth

Increased security of supply

End-user security

CUSTOMER RELATIONSHIP AND SEGMENTS

Domestic users

private house owner tenant	Private house owner Lessor Housing associations Housing cooperatives

Commercial customers

office building public building	Local authorities Building owner

COST STRUCTURE

- Hydraulic Components
- Electronic Components
- Heat Pumps
- Heat Recovery Components
- Connection to DH
- Pumps
- Adaptation of the supplier's
- Heating system (if prosumer)
- Construction and adaptation costs

Payment for recovered heat

Electricity for pumps and heat pumps

Administrative costs

Maintenance costs

REVENUE STRUCTURE

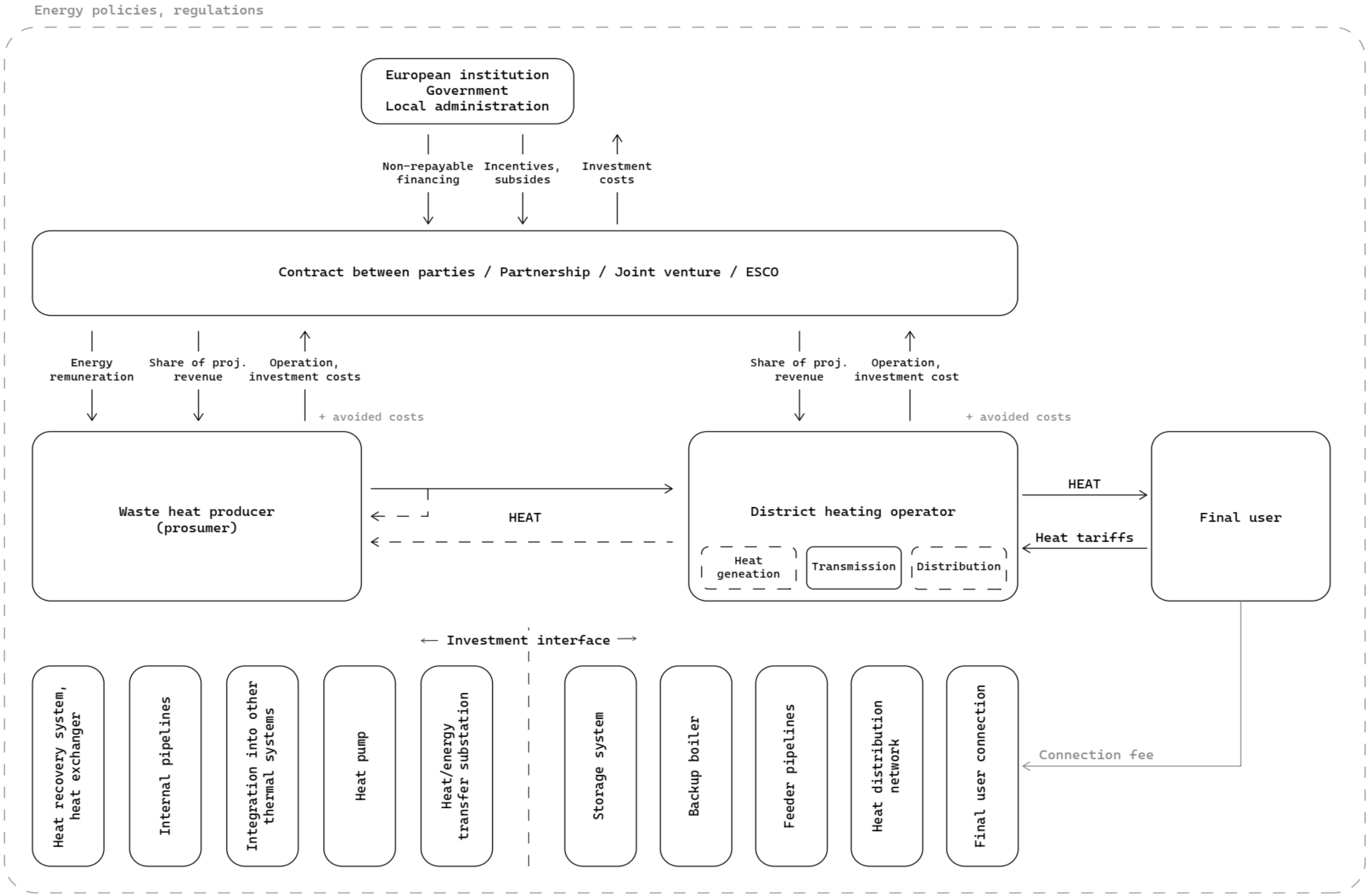
New customer connection:

- fixed tariff
- variable tariff
- metering tariff
- heat exchanger tariff

Avoided costs from alternative system replacement

Incentives and tax deductions

Investment agreement



Economic evaluation of heat

LIFE 4 HEAT RECOVERY

Payment Type	Case		
Operational Parameters (temperature, continuity…)			
Marginal Cost (MC)	IT		
Seasonal Pricing			
Levelized Cost of Heat (LCOH)	IT, NL, DK		
Excess Heat at Zero Cost	IT, NL, DK		Not always financially optimal
Targets for Clean Heat			
Indexation to the Best Next Alternative (gas, pellet…)	IT, NL		Subject to changes in market prices

Selvakkumaran et al. (2021), Liu et al. (2021)

THE LIFE4HeatRecovery PROJECT

Waste heat mapping

Maps & District Heating

LIFE 4 HEAT RECOVERY

The importance of using **maps** in district heating planning and design

They can provide a **visual representation of the physical characteristics of a district**, including the location and orientation of buildings, roads, utilities, and other infrastructure. This information is critical to the design and planning of district heating systems.

They can also be used to **identify potential heat sources** (such as industrial processes with excess heat) **and potential new customers for district heating system** (such as residential or commercial buildings).

They can help district heating planners and engineers to **identify potential challenges or constraints in the district** that may affect the design and implementation of the system, such as natural features, zoning restrictions, or access to existing infrastructure.

QGIS plugin for waste heat mapping

Within the LIFE4HeatRecovery project EURAC developed a QGIS plugin for waste heat (WH) mapping. The plugin facilitates the **identification of territories that are suitable for the implementation of technologies focused on heat and energy recovery**. These territories can be tagged as "eligible," providing valuable insights for decision-making and planning processes.

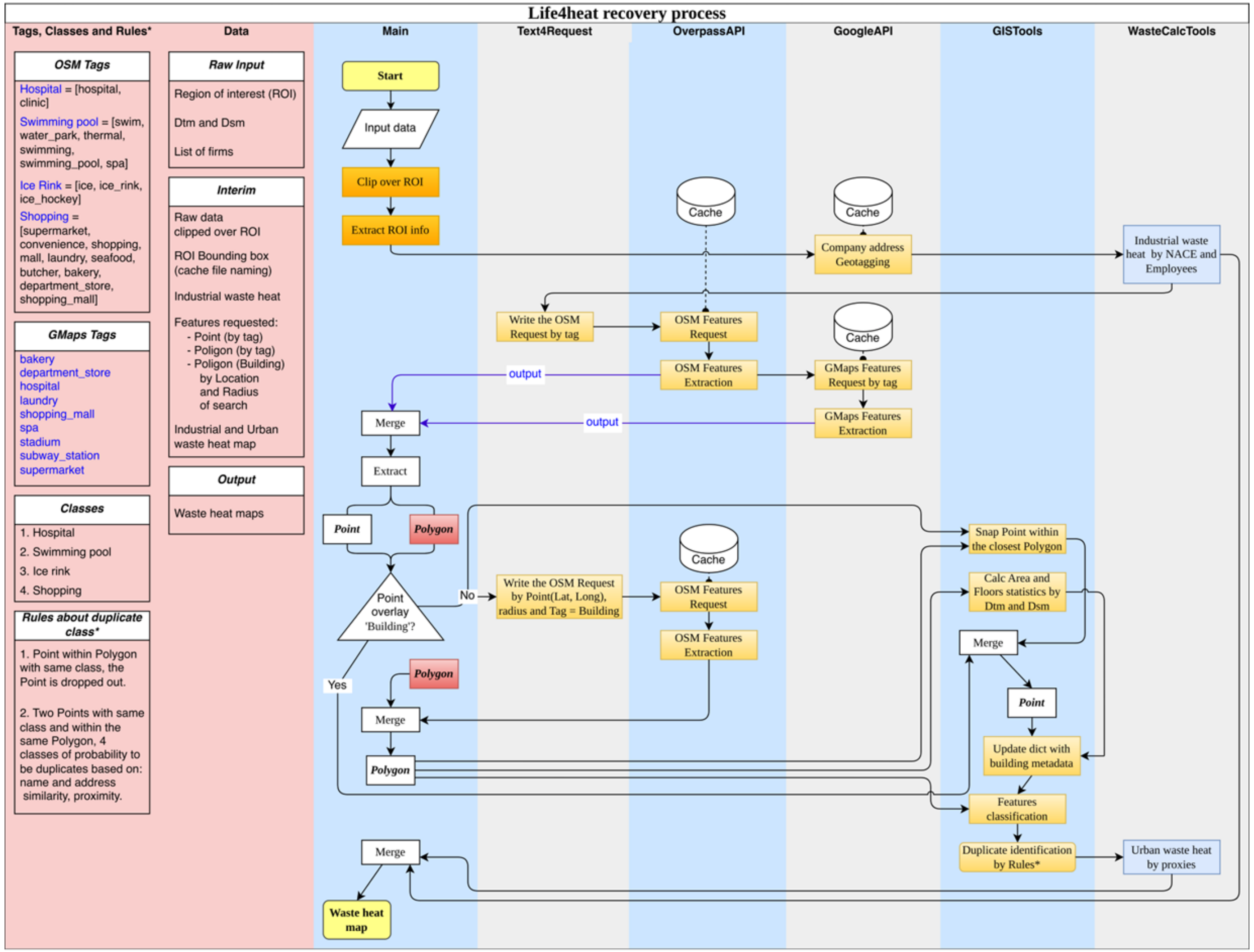
The waste heat sources mapped come from the Urban and Industrial area:

- Supermarket, mall and grocery
- Swimming pool and water-related recreational centres like ice-rinks
- Bakery and butcher
- Industrial firms

The waste heat is estimated using:

- Proxies (e.g., size of the building) and literature coefficients for **Urban waste heat**
- Coefficients related to the firm economic class (NACE code) and number of employees for **Industrial waste heat**

QGIS plugin for waste heat mapping: workflow



THE LIFE4HeatRecovery PROJECT

Partner cities and feasibility studies

Partner cities in LIFE4HeatRecovery

LIFE4HeatRecovery involved **partner cities** to make simplified feasibility studies for waste heat recovery measures in local district heating networks. Here, a description of the general methodology is presented.

<u>Goal:</u>

- Make the district heating system more efficient

<u>Tasks:</u>

- Planning district heating decarbonization evaluating the integration of waste heat sources
- Planning district heating network expansion by integrating new customers and sources

<u>Partner cities in the LIFE4HeatRecovery project:</u>

- Castegnato (Italy)
- Brunssum (the Netherlands)
- Plymouth (UK)

Partner cities: workflow

LIFE 4 HEAT RECOVERY

Analysis of the current state

To understand the weaknesses of the system, it is necessary to carefully analyse the starting scenario:

- Network geometry analysis
- Network temperatures
- Heat production and selling
- Energy prices and investment costs
- Non-connected users nearby

Waste heat mapping and filtering

Plug-in use for assessing potential sources of waste heat in the Region Of Interest (ROI).
Of all the mapped sources, the most interesting ones must be selected based on:

- Proximity to the network
- NACE code and company size -> amount of available waste heat

Analysis for waste heat integration

Analysis for new customers integration

The integration of waste heat is also strongly related to the total heat demand of the network, and thus to the number of connected users. When analysing new scenarios, if new users are expected to be connected then there is a greater possibility of integrating new waste heat sources.

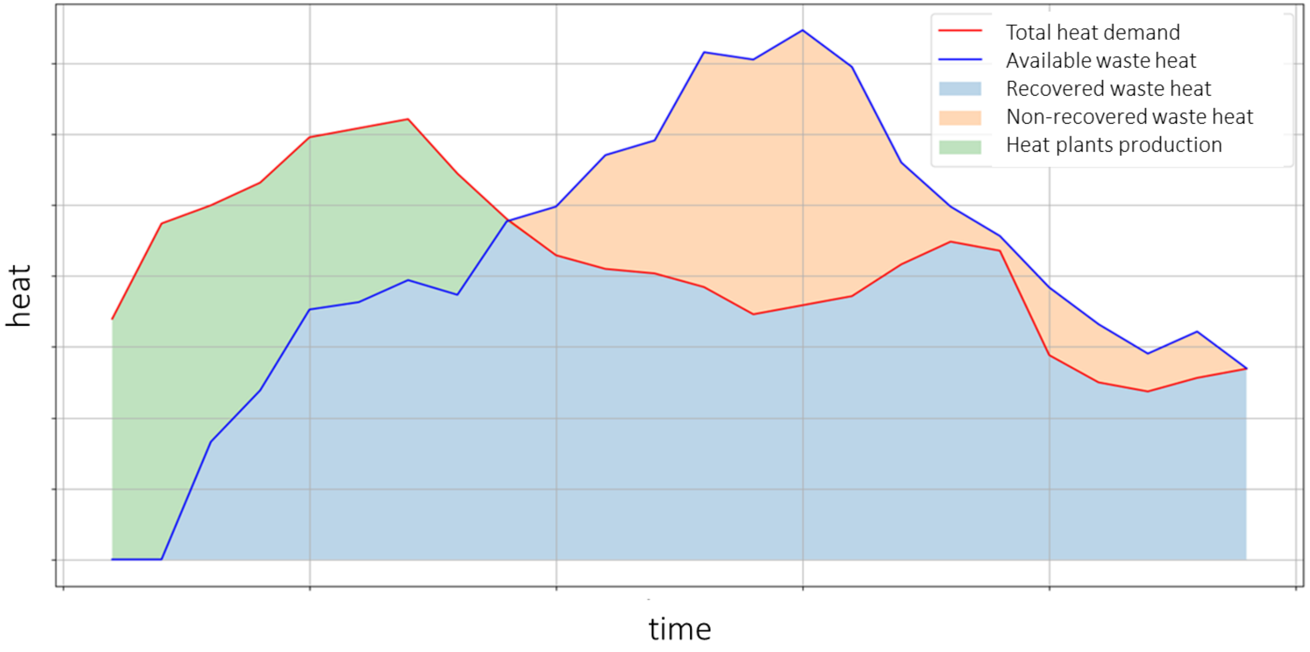
Technical-economic comparison analysis

For the different scenarios investigated and proposed, it is necessary to carry out comparison analysis with the starting scenario and other possible solutions (e.g., individual heat pumps).
For energy prices, the projection over time must be considered.

Waste heat integration and network expansion

It is necessary to consider the temporal profiles, at least on an hourly basis, of total heat demand (heat losses and heat required by the users) and waste heat availability in order to estimate the amount of waste heat that can actually be recovered (blue area).

The figure shows a generic example of a network without heat storage. The presence of the latter can make it possible to store excess waste heat (orange area) and to use it at different times by decreasing the heat production of the thermal power plants (green area).



Construction of temporal profiles

LIFE 4 HEAT RECOVERY

Typically, the network operator has monitoring data (with very detailed timestamps, e.g., in the order of 5-10 minutes) concerning **pumping stations and thermal power plants**.
On the user side, heat consumption is certainly monitored in order to apply sales tariffs. In some cases, monitoring on the **user side** can also be very detailed (timestamps of no more than 1 hour).
If these data are not available, estimations must be made.

Heat demand of users

Space heating: the normalised profile can be obtained based on degree days.
Appropriate statistical variability could be introduced to consider the different thermo-physical behaviour and heating systems of the connected buildings.

Domestic hot water: different normalised consumption profiles per building usage can be found in the literature.

Thermal losses of the network

$$Q_{loss}(\theta) = UA_{ntw} \cdot \left(\overline{T}_{ntw}(\theta) - T_g(\theta)\right) \cdot f_{loss}$$

Q_{loss}: thermal losses.

UA_{ntw}: overall heat loss coefficient of the network, calculated according to the type and geometry of the various pipe sections.

$\overline{T}_{ntw}$: average temperature of the network, considering supply and return line.

T_g: ground temperature.

f_{loss}: calibration factor to be computed based on monitoring data.

Waste heat availability

Normalised profiles of waste heat availability can be estimated based on the typology of source:

- Supermarket
- Factory
- Shopping mall
- Sport facilities

Annual quantities are instead available from the QGIS plug-in.

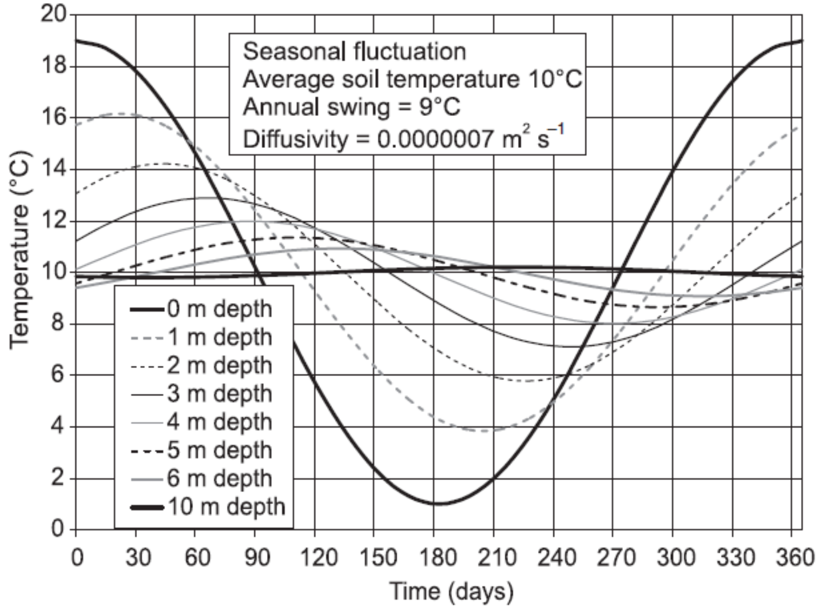
Ground temperature estimation

Williams and Gold (1976) gave an excellent description of how we can calculate the response of ground temperatures to daily or seasonal temperature cycles. They stated that

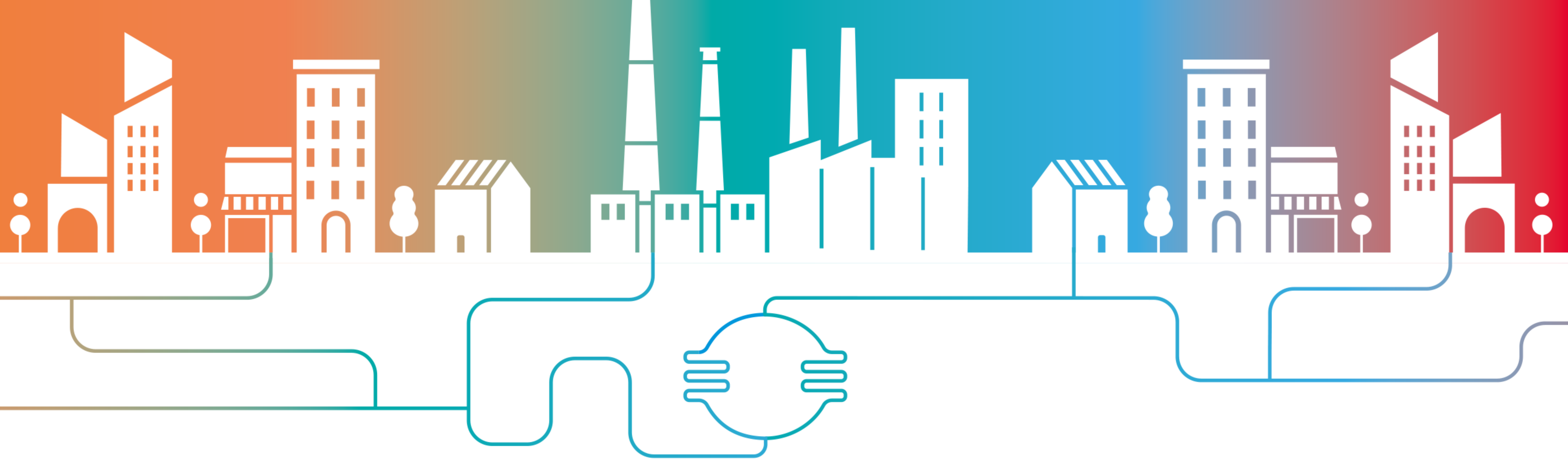
$$\theta(z,t) = \bar{\theta} + A \cdot \exp\left(-z\sqrt{\frac{\pi}{\alpha t_o}}\right)\cos\left(\frac{2\pi t}{t_o} - z\sqrt{\frac{\pi}{\alpha t_o}}\right)$$

where
$\theta(z,t)$ is the temperature at depth z and time t;

α = thermal diffusivity
$\bar{\theta}$ = the average ground temperature;
A = the amplitude of the temperature variation at the ground surface (maximum – average). If we are talking about seasonal variations, this is called the annual soil temperature *swing*;
t_o = the duration of a full cycle of temperature (24 h for a diurnal cycle, 1 year for a seasonal cycle).



Source:
David Banks - An Introduction to Thermogeology - Ground Source Heating and Cooling, 2nd Edition (2012)



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LIFE 4 HEAT RECOVERY