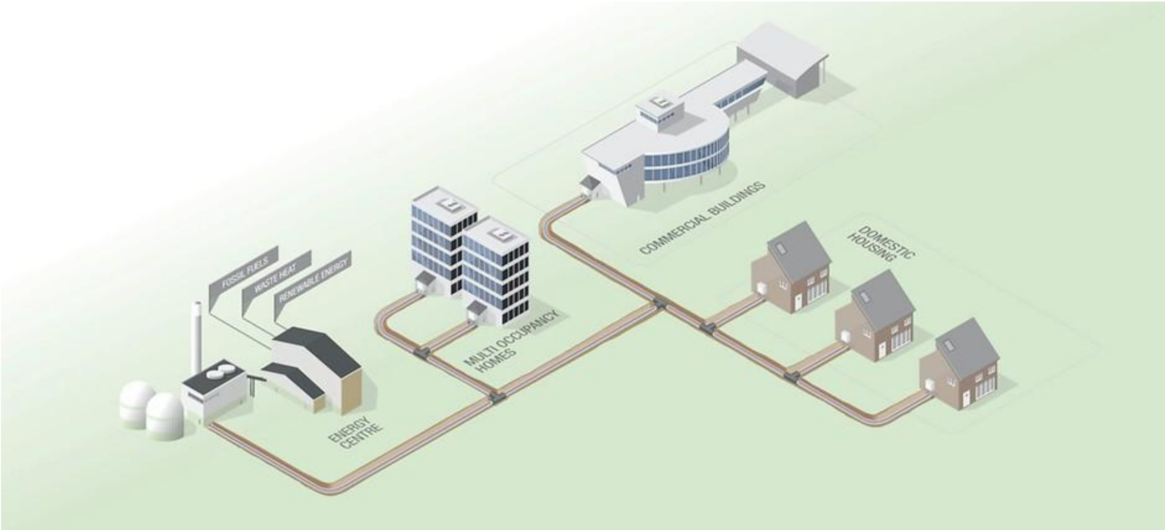
District heating and cooling systems

HEATING VENTILATION AIR CONDITIONING SYSTEMS
20-05-2025
Jacopo Vivian

What is it?

Characteristics



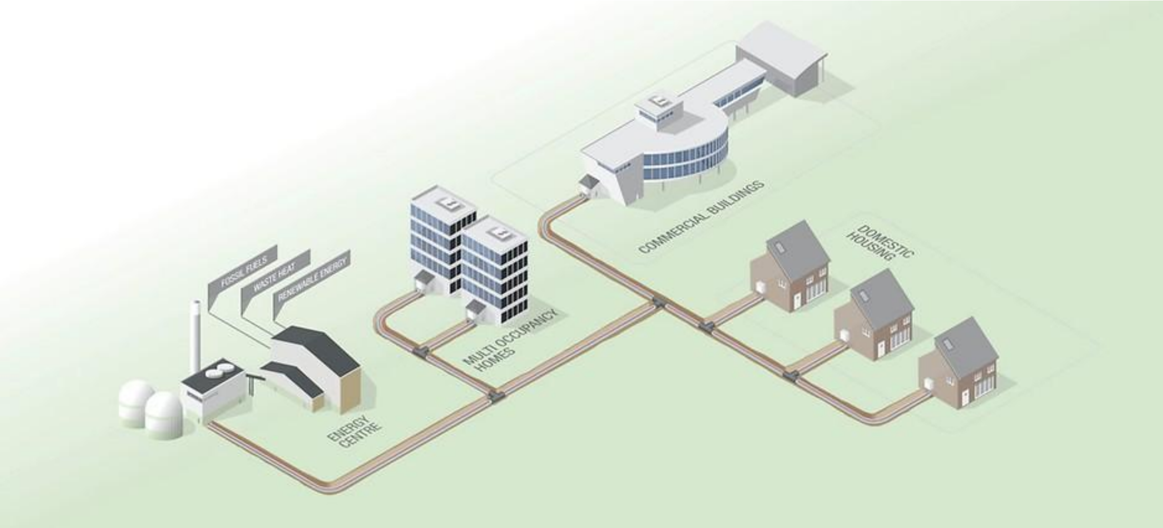
[Source: *https://www.rehau.com/*]

1) Networked, local system
2) Heating, cooling or both
3) Public → requires political action
4) Heat recovery from waste heat and renewables

What is it?

Characteristics

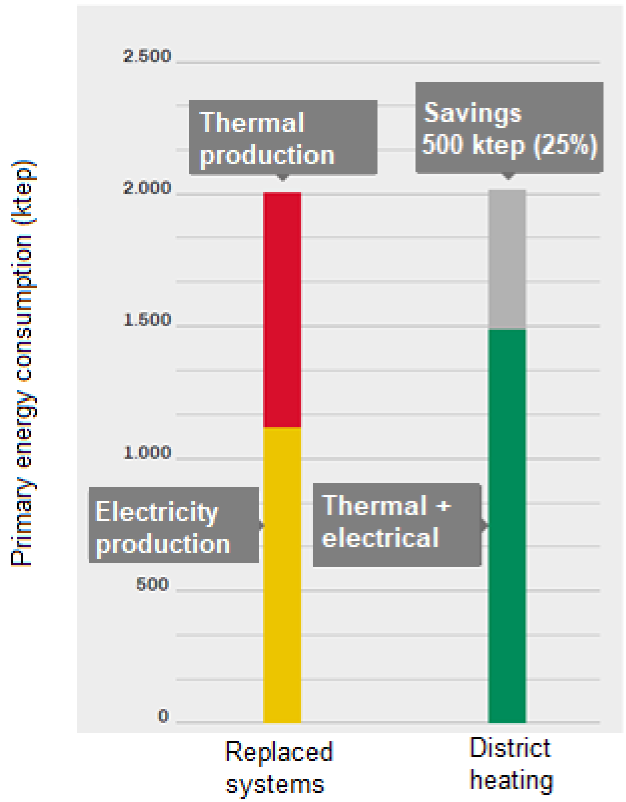
1) Supply station(s)
2) Distribution system
3) Substations

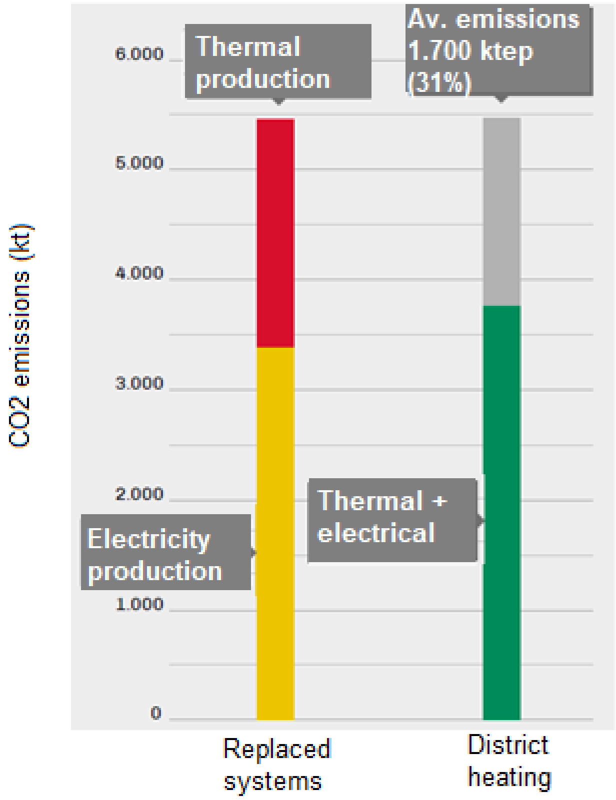


[Source: *https://www.rehau.com/*]

Why do we need DH?

Advantage





[Source: *Annuario AIRU 2021*]

Who are the typical users?

FIGURA 4 Volumetria teleriscaldata distinta per tipologia d'utenza

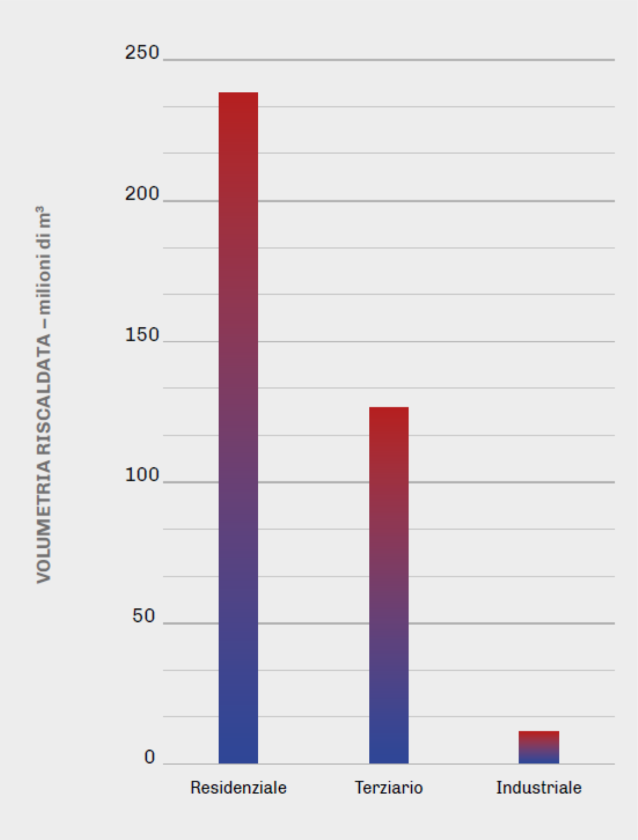
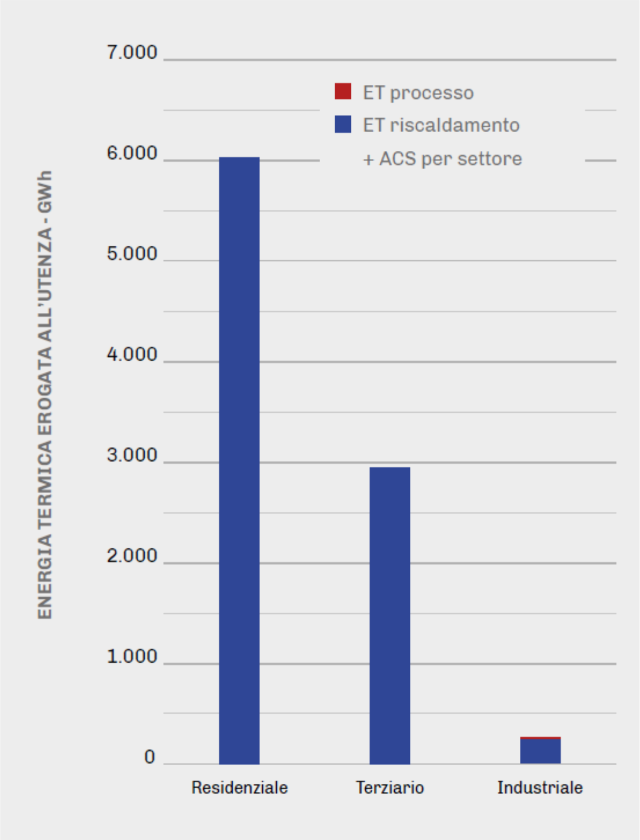


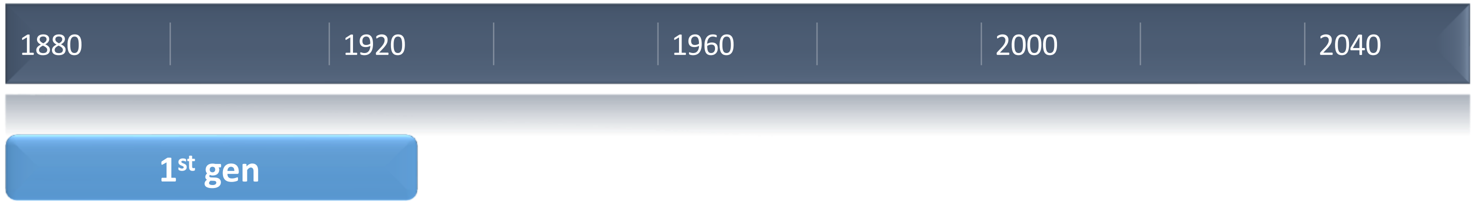
FIGURA 5 Energia termica erogata distinta per tipologia d'utenza



[Source: *Annuario AIRU 2021*]

A bit of history

First generation



Where: New York, Paris..
Why: replace polluting coal boilers in big cities
Heat carrier fluid: Steam
Characteristics:
Steam leakage, huge heat losses, corrosion

A bit of history

Second generation

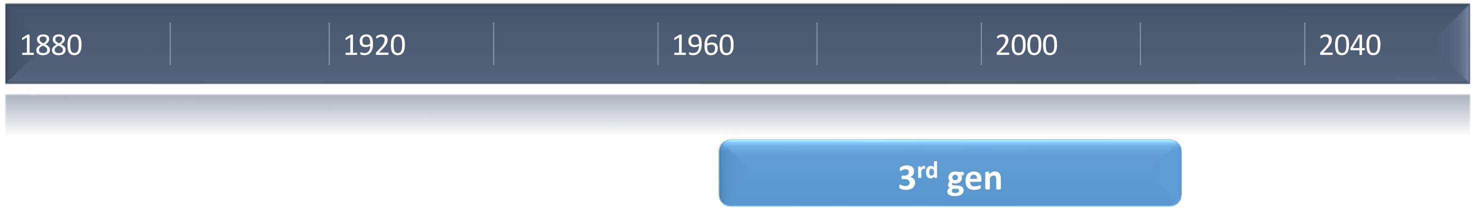
1880 | 1920 | 1960 | 2000 | 2040

2^{nd} gen

Where: URSS
Why: Planned economy
Heat carrier fluid:
Superheated water (>100°C)
Characteristics:
Oversized pipes with no thermal insulation
«Production-driven» regulation

A bit of history

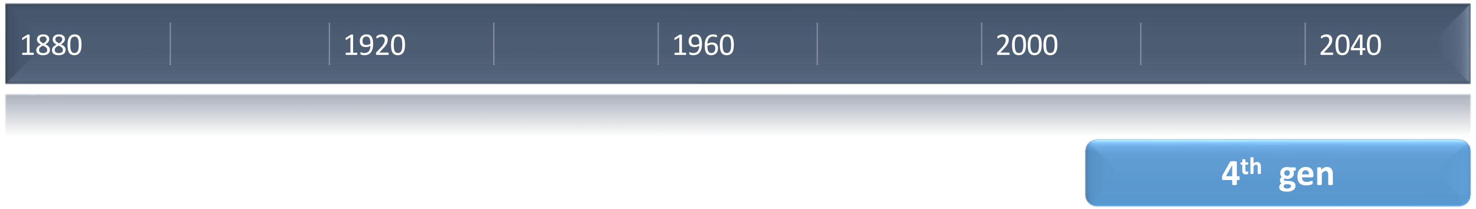
Third generation



Where: Scandinavian countries
Why: Efficiency and energy security concerns
Heat carrier fluid:
Hot water (90/60°C)
Characteristics:
Pre-insulated pipes
«Demand-driven» regulation

A bit of history

Fourth generation



Where: Scandinavian countries
Why: Heat demand reduction, renewables
Heat carrier fluid:
Hot water (70/40°C)
Characteristics:
Increased supply from renewable heat,
use of twin pipes
«Demand-driven» regulation

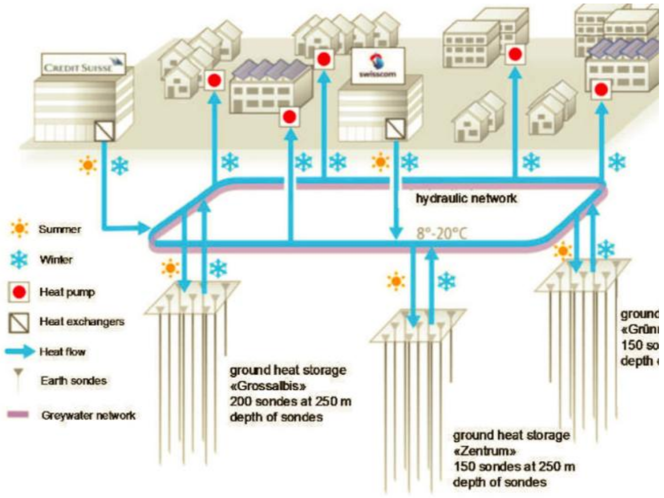
A bit of history

Fifth generation

1880 | 1920 | 1960 | 2000 | 2040

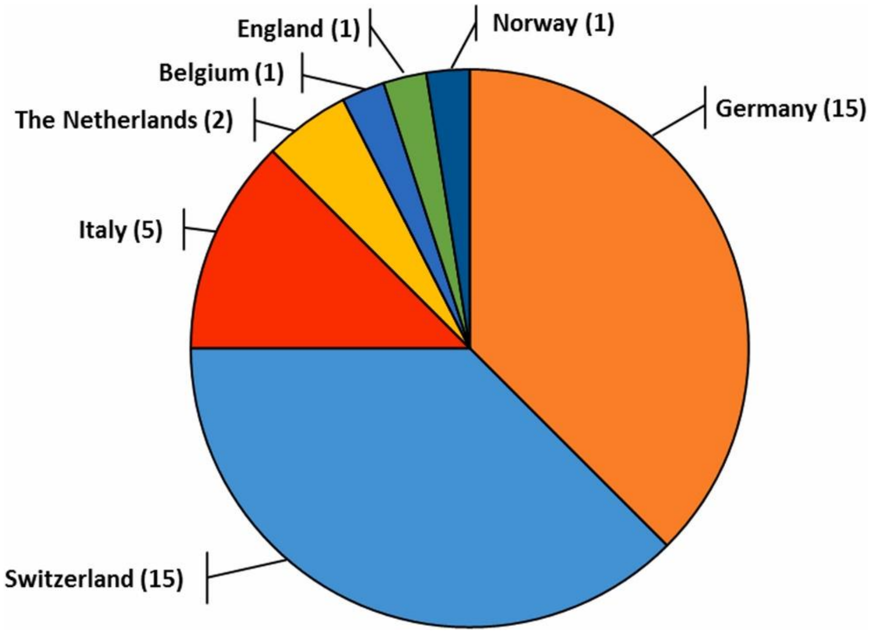
5th gen

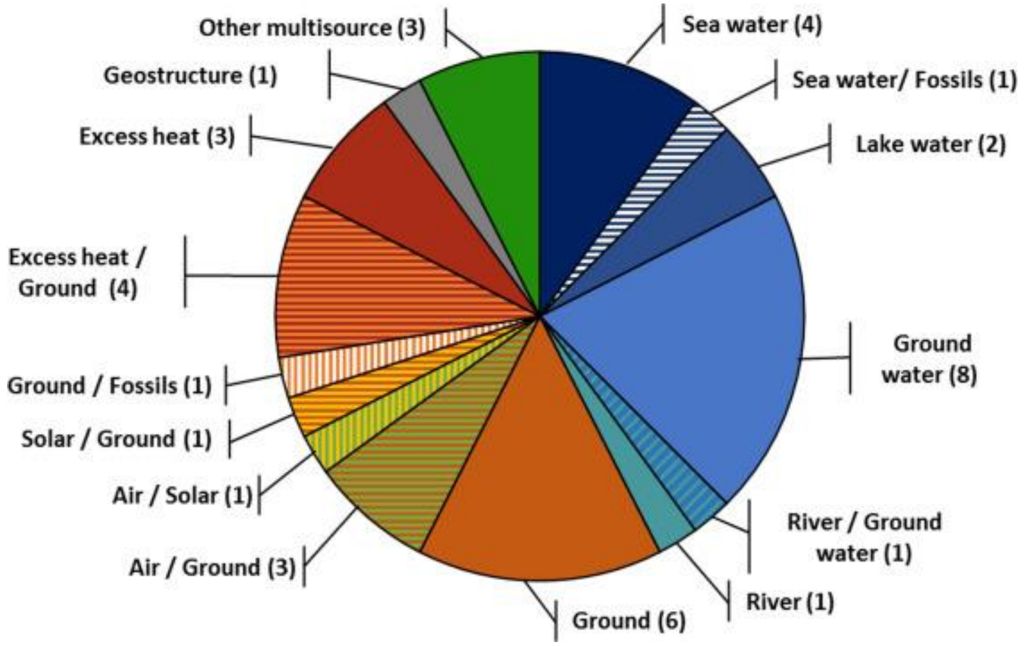
Where: Western Europe
Why: Heat demand reduction, renewables
Heat carrier fluid:
Ambient/low temperature water (<50°C)
Characteristics:
Decentralized reversible heat pumps
Simultaneous heating and cooling possible
Free floating temperature in the loop



A bit of history

Fifth generation





[Source: *Buffa et al, 2019*]

Economic feasibility

Linear heat density

Ratio between annual heat demand and length of the (transmission) pipes

$$d = \frac{E_T(MWh)}{l_{net}(m)}$$

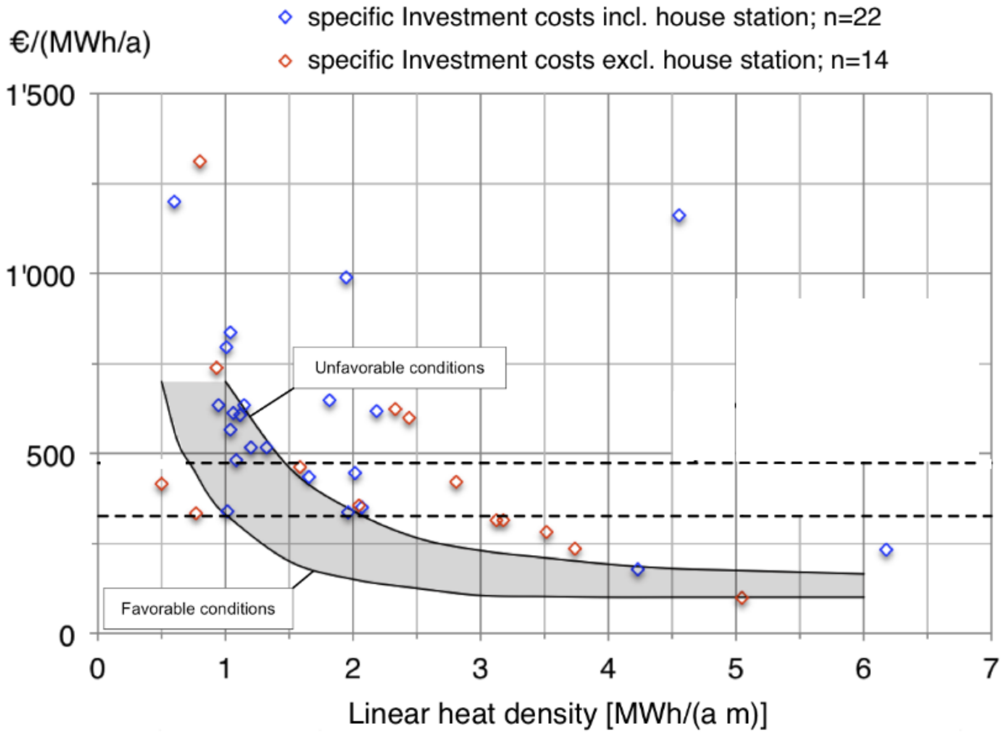
	Energy delivered to the buildings (MWh)	Overall network length (km)	Linear heat density (MWh/m)
Asiago	9’711	13.47	0.72
Brescia DH	981’194	379.8	2.58
Brescia DC	32’122	7.91	4.06
Ferrara	134’816	82.58	1.63
Forni di Sopra	1’614	3.08	0.52
San Martino di Castrozza	17’727	15.19	1.17
Verona	260’395	80.63	3.23
Vicenza	38’967	23.15	1.68
Torino	1’790’025	598.66	2.99

Economic feasibility

Linear heat density

Ratio between annual heat demand and length of the pipes

$$d = \frac{E_T(MWh)}{l_{net}(m)}$$



[Fonte: *Status Report on District Heating Systems in IEA Countries, 2014*]

Economic feasibility

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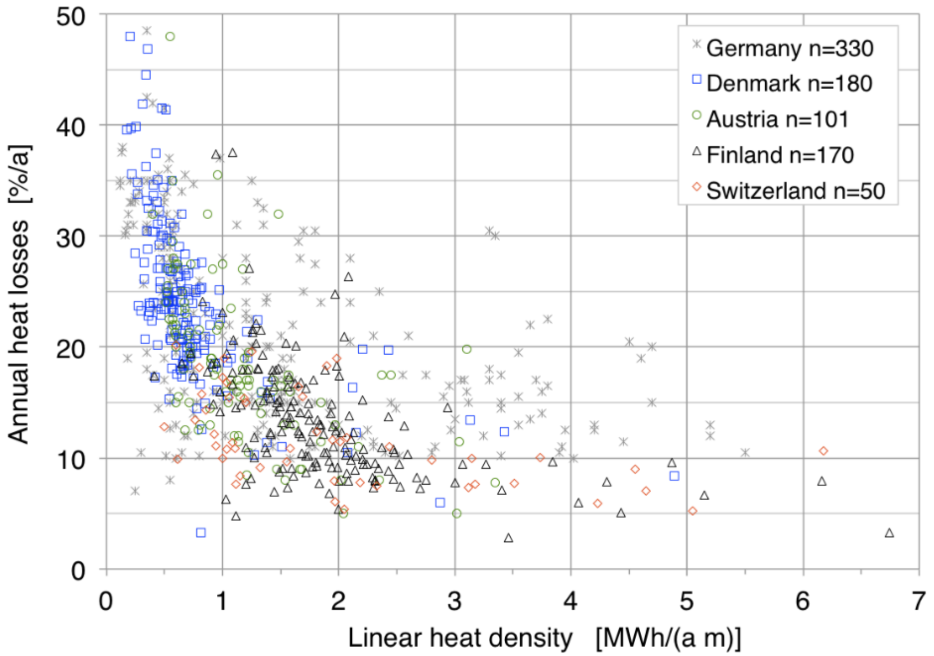
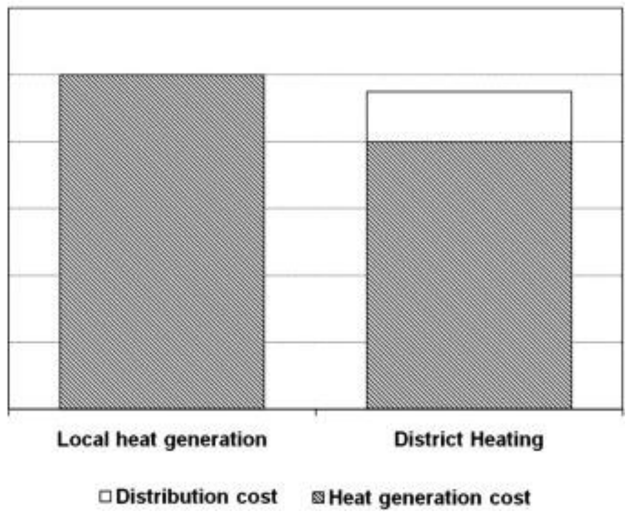


[Fonte: *Status Report on District Heating Systems in IEA Countries, 2014*]

Economic feasibility

Distribution network

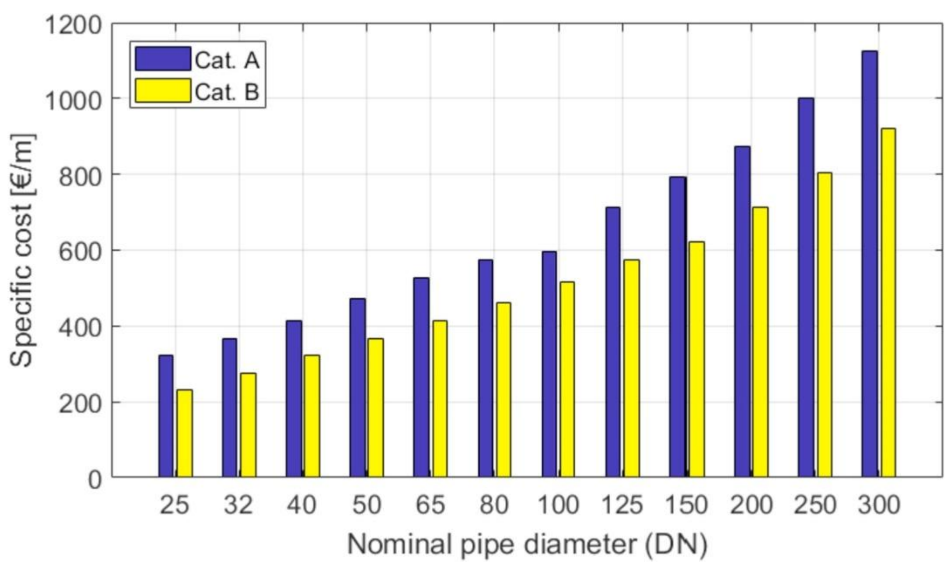
Heat tariff (€/MWh) for the final user must be the same (or lower) than that of alternative individual heat supply solutions (e.g. gas boilers). Therefore, heat generation cost for the utility must be lower than that of domestic users.

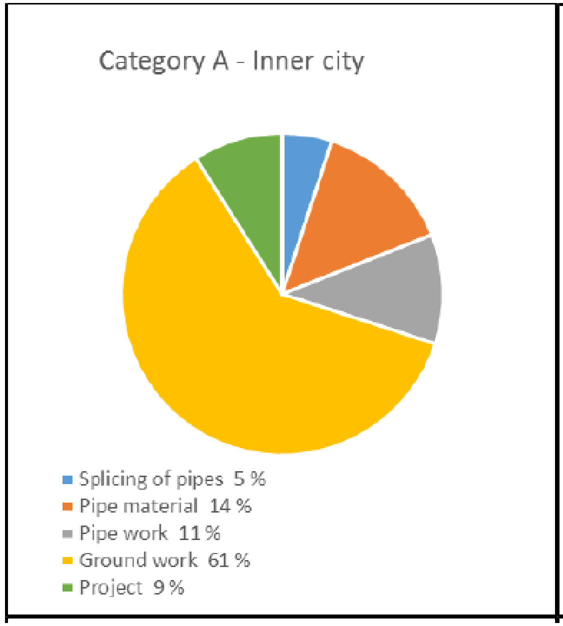


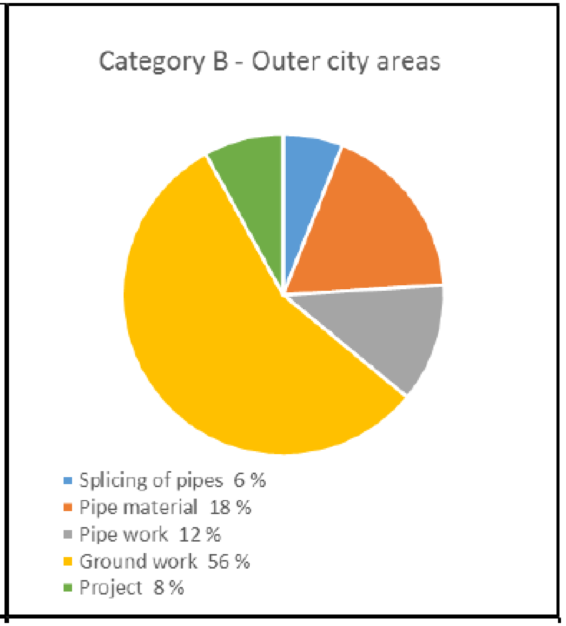
[Fonte: *Persson & Werner, 2011*]

System design

Distribution network







System design

Distribution network

In order to size the district heating network pipes, the following procedure can be followed:

1) Estimate target heat demand and peak load of the connected buildings + heat losses (kW)
2) Use nominal ΔT (e.g. 20-30 K) to find corresponding mass flow rate
3) Calculate diameter with either constant velocity (e.g. 0.65 m/s) or constant pressure loss (e.g. 150 Pa/m)

System design

Distribution network

Steel

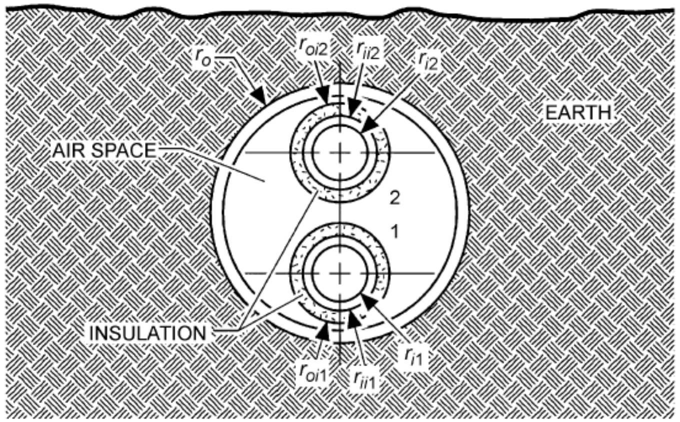
- *Advantages*: High strength and good flexibility, can be joined by welding for a high-integrity joint that can be inspected for quality control, widely available in all sizes, familiar material to most workforces.
- *Disadvantages*: Relatively high cost, highly susceptible to corrosion and will require corrosion protection. Skilled labor force required for welding. Slower installation, especially in larger diameters.

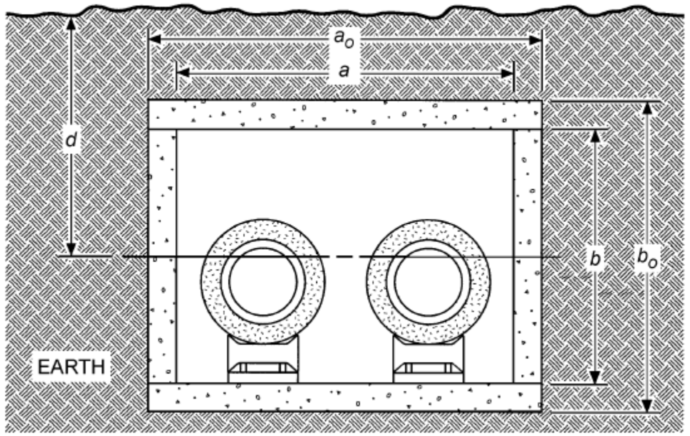
PE and HDPE

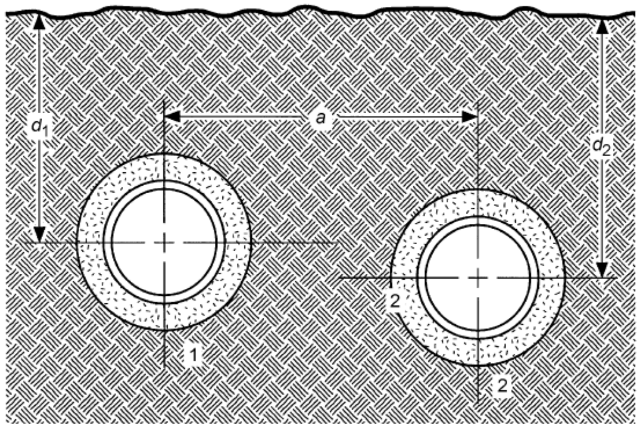
- *Advantages*: Low weight, very flexible, can be fusion welded for high-integrity joints, available in sizes up to 1.6 m. Leak free and fully restrained (no anchor blocks).
- *Disadvantages*: Low strength compared to steel results in significant wall thickness and thus cost in larger diameters. Increased wall thickness also reduces inside diameter, which results in higher pressure losses and may require larger sizes for the same flow rates. Larger-diameter fusion welding machines may be of limited availability. Cost fluctuates with oil price.

System design

Distribution network







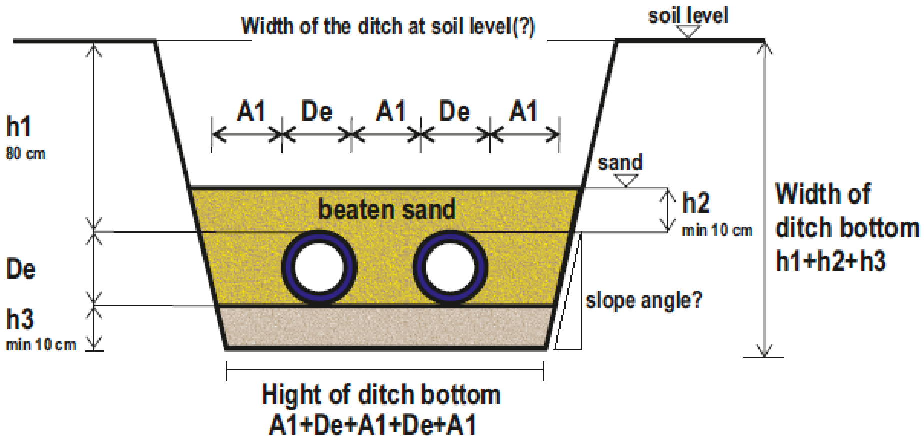
System design

Distribution network

Table about installation centre distance

Dimensions	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm
De Casing PE	90	110	125	140	160	200	225	250	315	400
A1 Installation centre distance	150	200	250	250	250	250	250	350	350	350

Typical heights in a ditch



Legend:

h1 = minimum height of the filling-up with riddled material from excavation debris, the 80cm height is the minimum value to prevent soil freezing, mechanical tamping with a vibrator with max. pressure 100Kpa

h2 = minimum height of sand layer above the pipes with mixed medium 0-4mm granulometry, manually tamped

h3 = minimum height of sand layer on the bottom of the excavation with mixed medium 0-4mm grain size, manually tamped

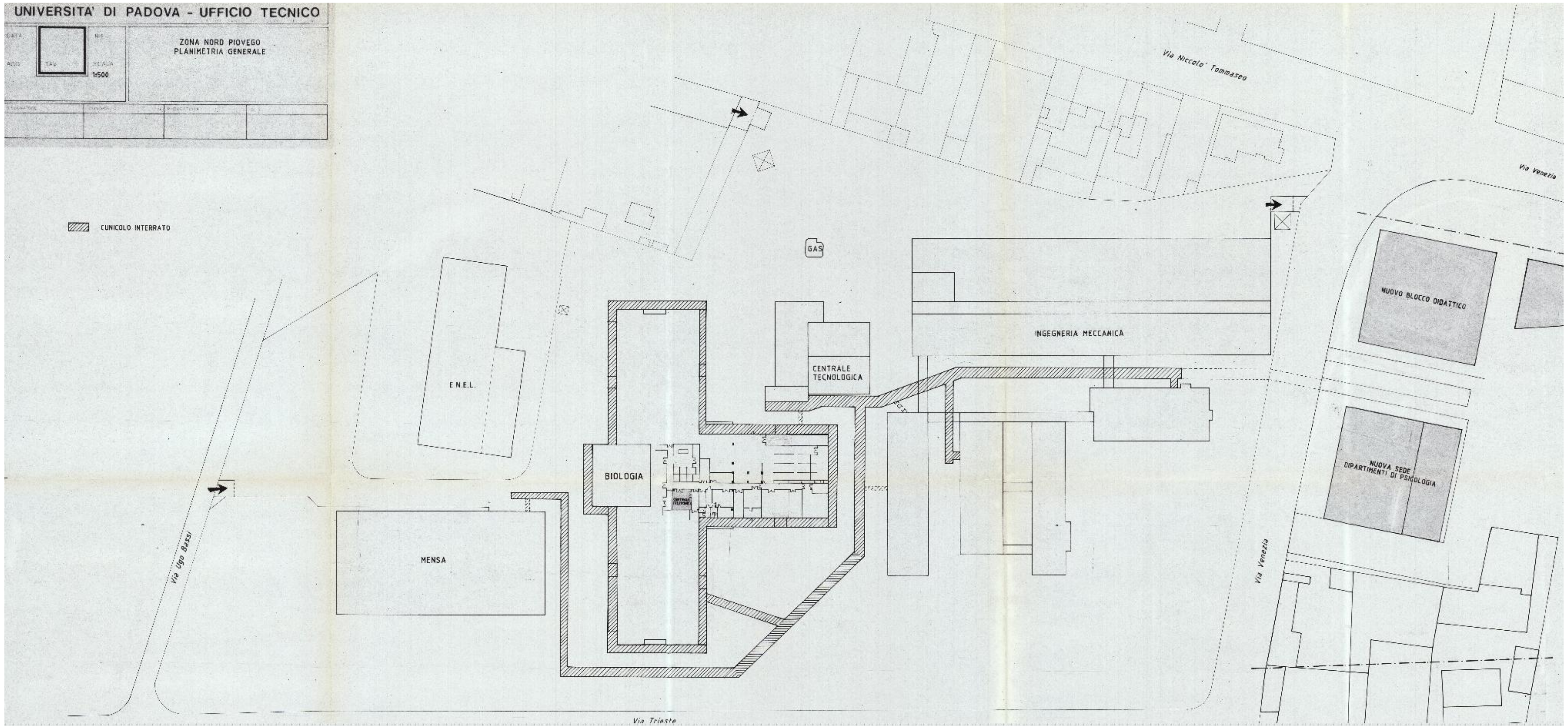
A1 = minimum distance to install the pipes for processing operations

De = outside diameter of the pipes

[Fonte: *https://www.aquatechnik.it/*]

System design

Example: Nord Piovego

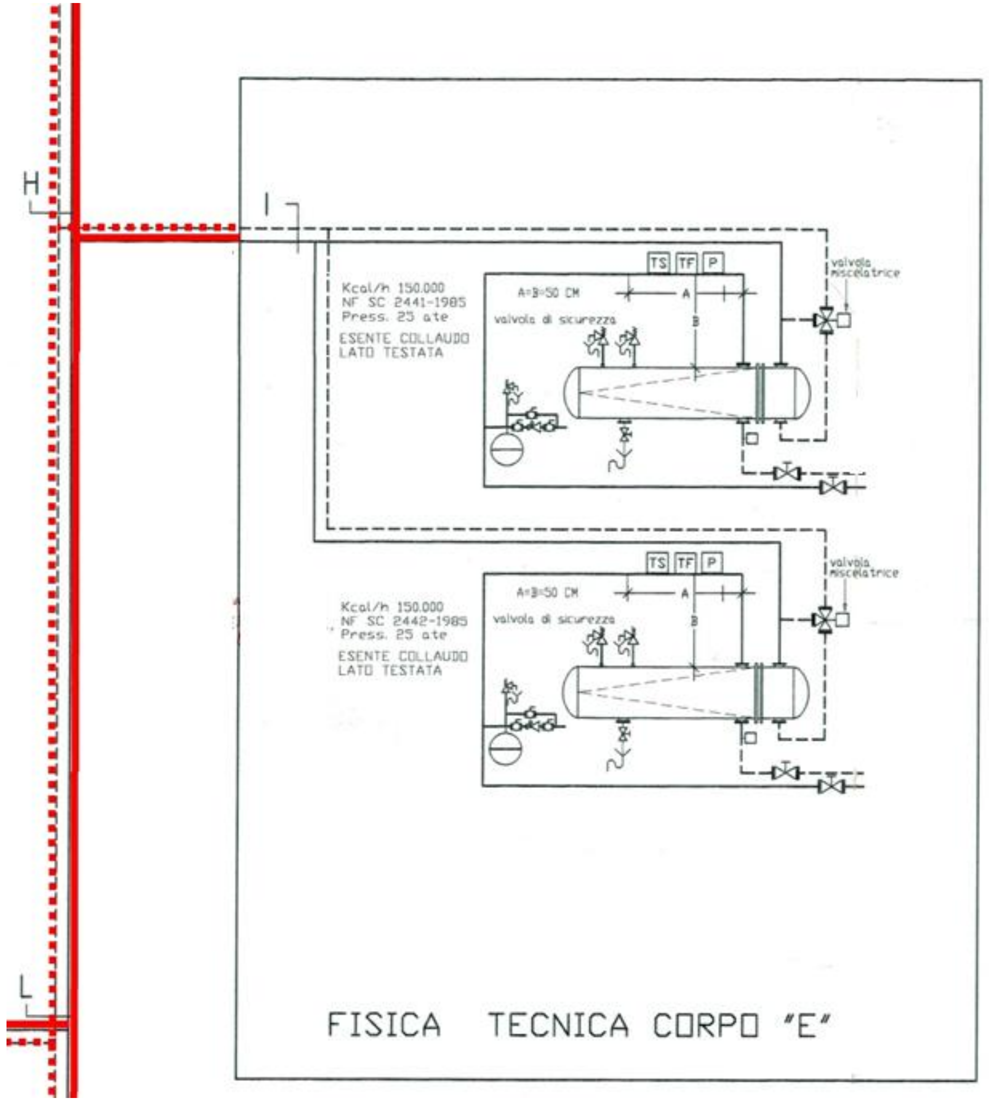


System design

Example: Nord Piovego

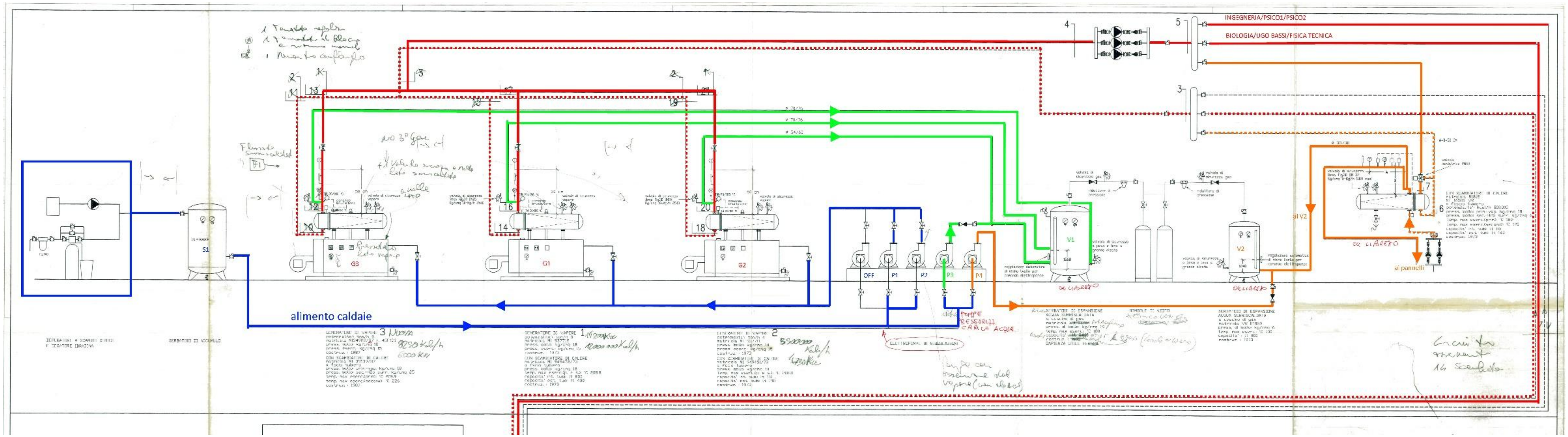
2nd generation network operated with constant flow.

Mixing valve on the return (primary side) of the heat exchangers regulates the flow rate depending on the building heat demand.



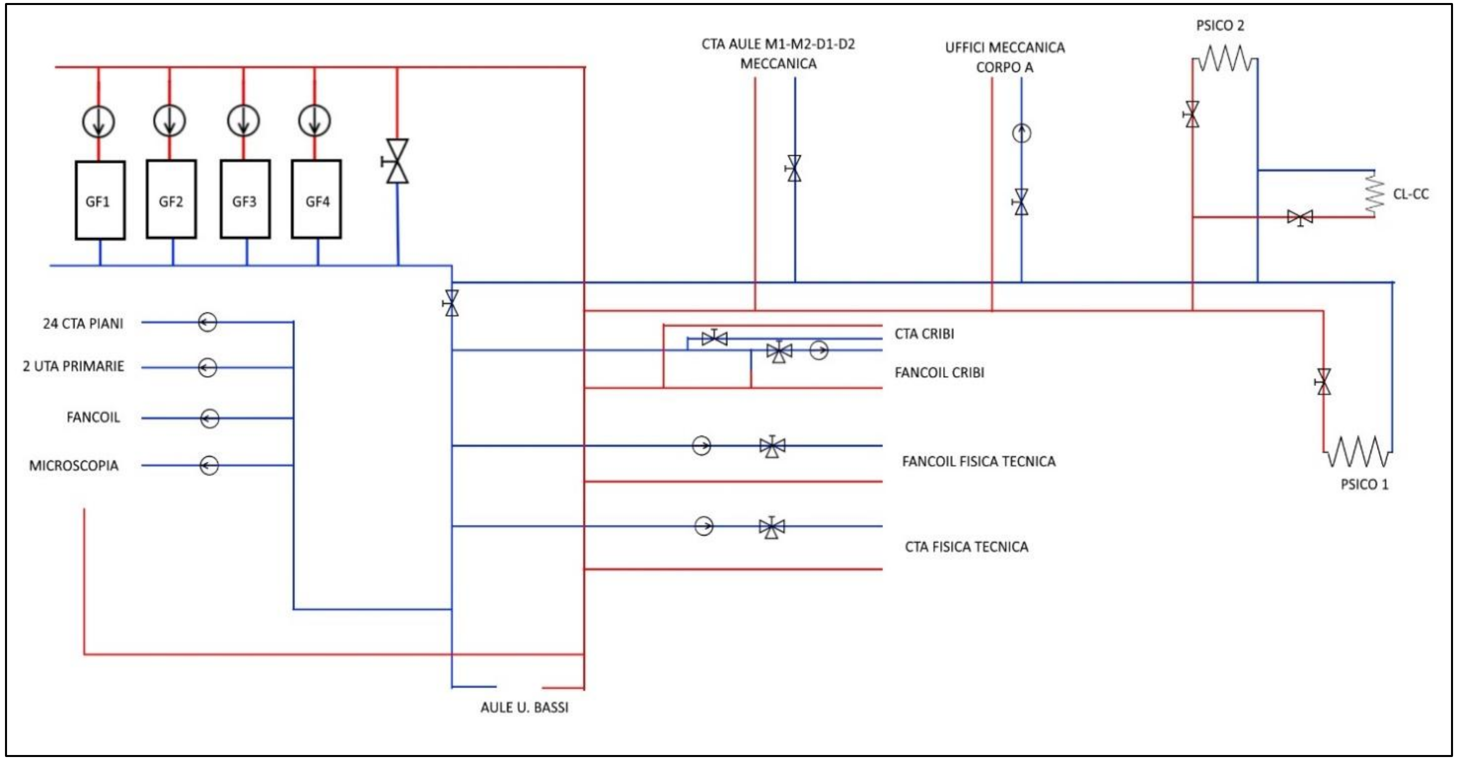
System design

Heat supply stations



System design

Cooling supply stations



System operation

Important characteristics

User substations

- Direct vs indirect connection
- SH-only, DHW-only, SH+DHW

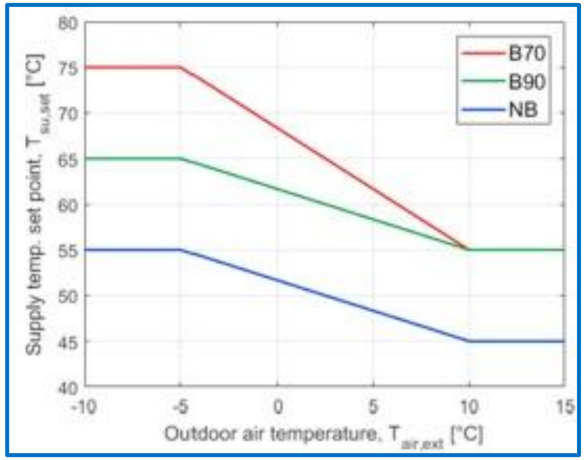
Heat supply station

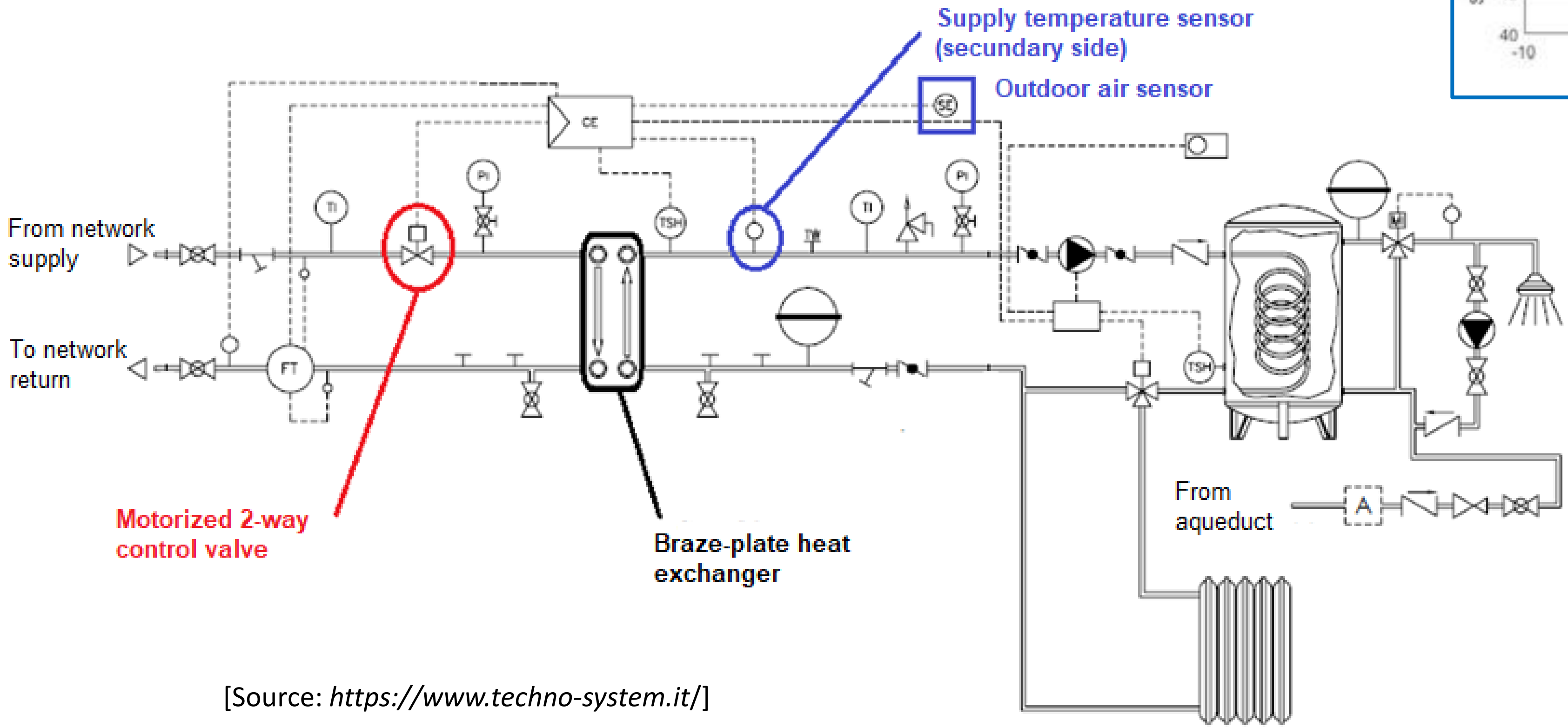
- Constant flow vs variable flow operation

System operation

User substations

$T_e \rightarrow T_{su,set}$

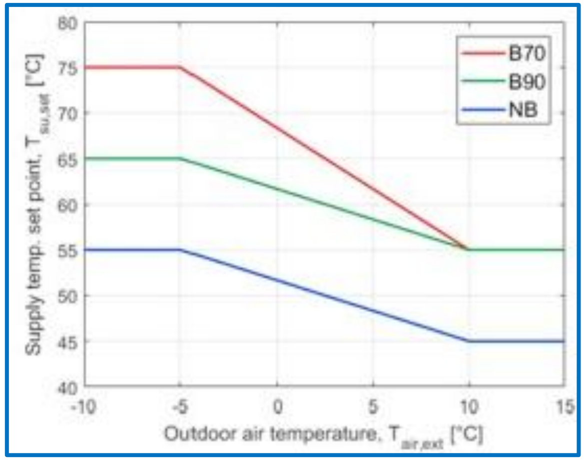




[Source: *https://www.techno-system.it/*]

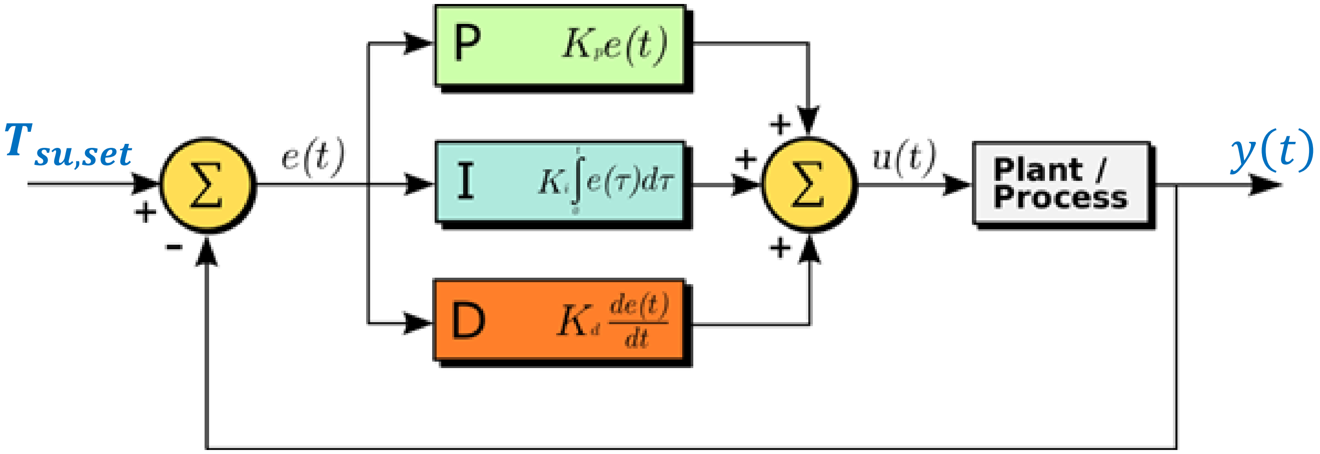
System operation

User substations



$$T_e(t) \rightarrow T_{su,set}(t)$$

$$e(t) = T_{su,meas}(t) - T_{su,set}(t)$$

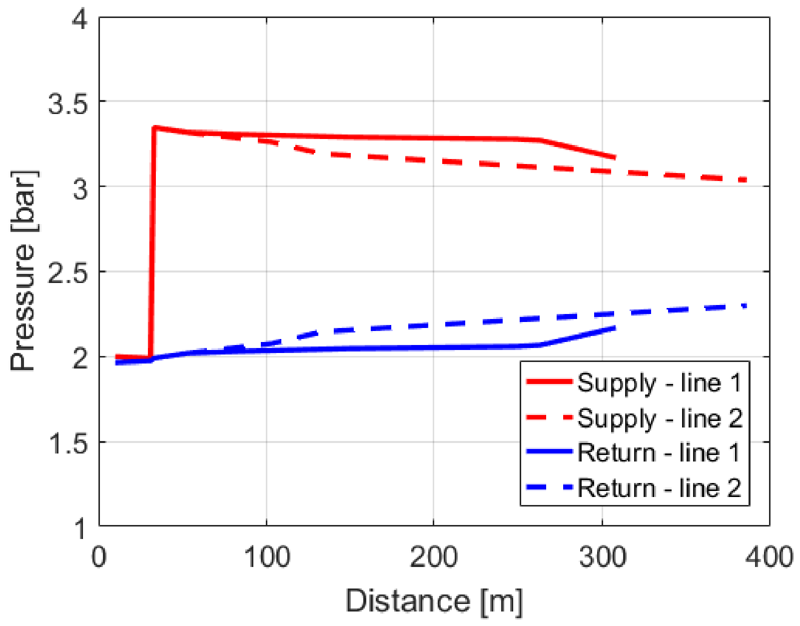


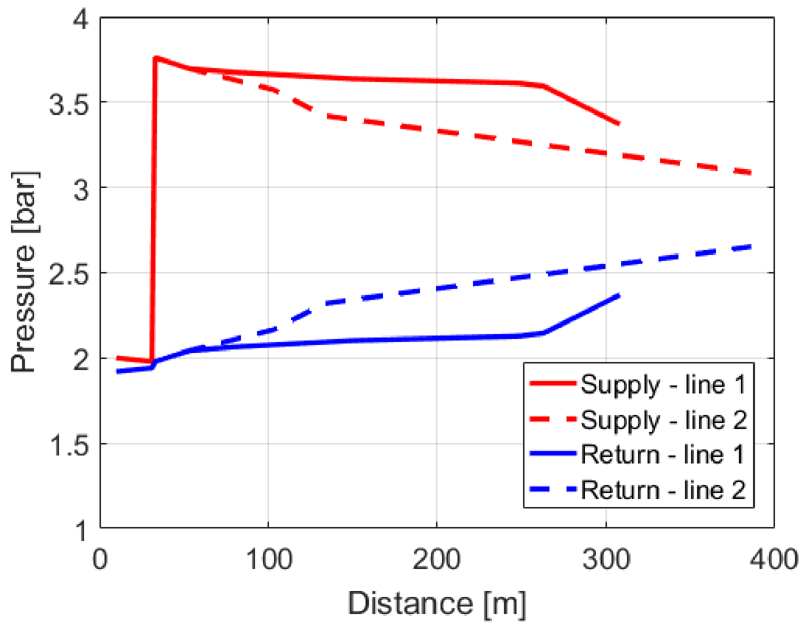
$$y(t) = T_{su,meas}(t)$$

System operation

Network

Example of pressure distribution with 2 lines and +50% mass flow (plot on the right)

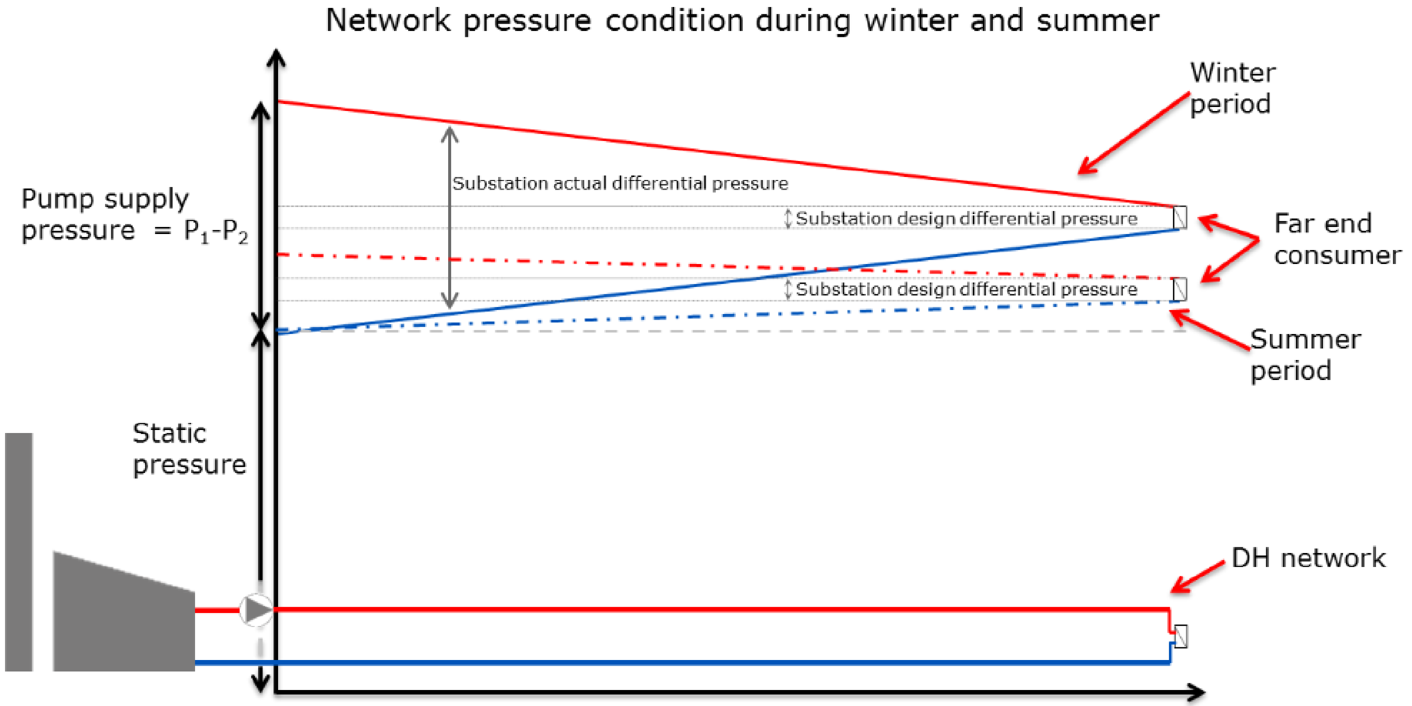




System operation

Network

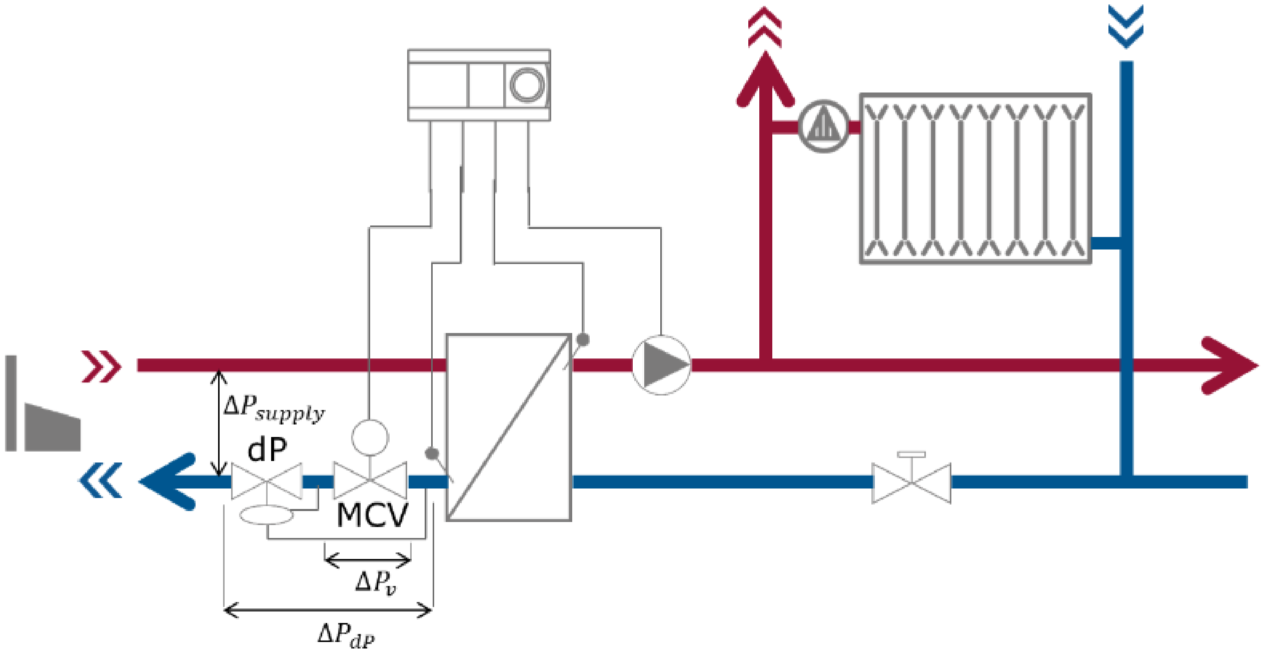
Example of pressure distribution from supply to critical user



System operation

User substation

Differential pressure controller ensures that the MCV regulates the flow with approximately constant ΔP at all network operating conditions.



[Source: *https://www.danfoss.com/*]

System operation

The **user** typically **“**calls” for heat when needed with a 2-way valve on the primary side, possibly with weather compensation (electronic control system needed).

DH operator

1) Ensure each customer, especially critical one, has $\Delta P > \Delta P_{min}$ (e.g. 150 kPa)
2) Save energy i.e. reduce flow rate (or supply temperature) when heat demand is low

System operation

Case study

Example from Verona Centro Città's network:

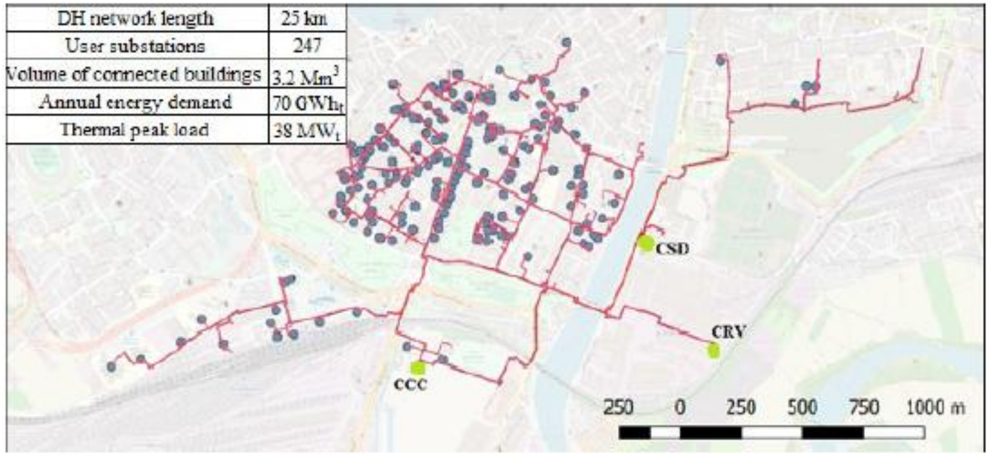


Figure 3.2 Plan of the district heating network of Verona Centro Città obtained with QGis [73] (the blue dots represent the substations and the green dots represent the supply stations).

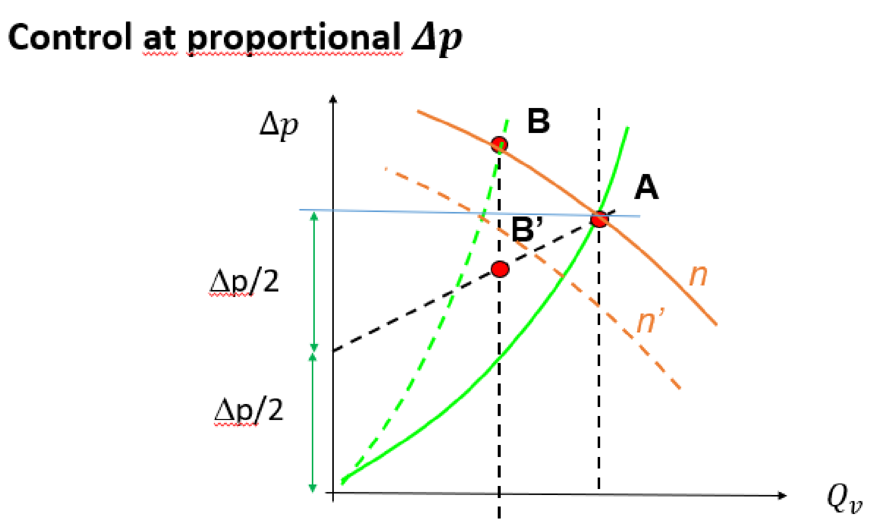
Table 3.1 Installed thermal and electrical power of the supply stations.

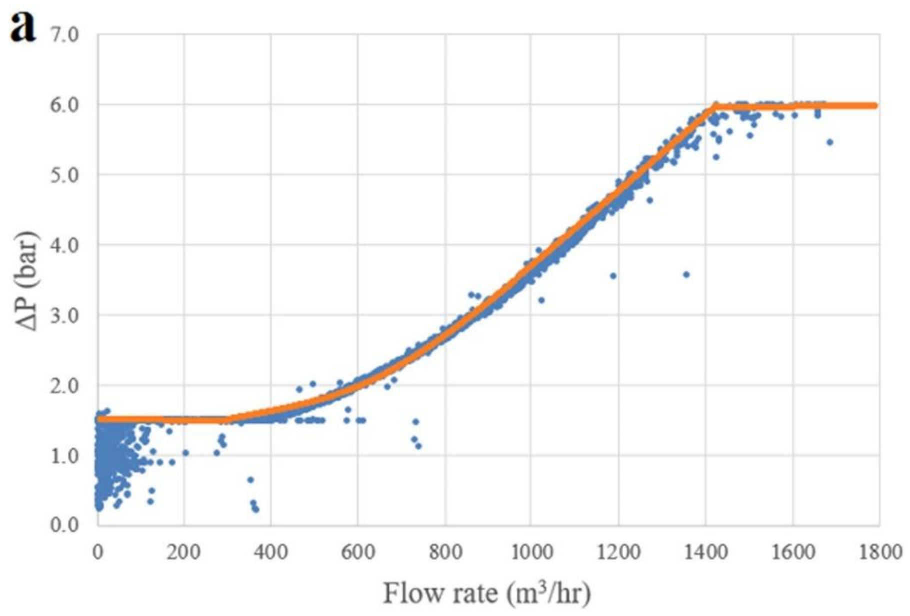
Supply station	Heat generation	Units	Total installed power
CCC	Gas-fired internal combustion engines	5	11 MW_{th} (11.25 MW_e)
	Heat pumps	5	2.0 MW_{th}
	Gas boilers	3	25.5 MW_{th}
CRV	Waste heat from foundry	1	1.1 MW_{th}
CSD	Gas boilers	3	3.4 MW_{th}

System operation

Case study

Variable flow control in main heat supply station. Example from Verona Centro Città's network:





System operation

Case study

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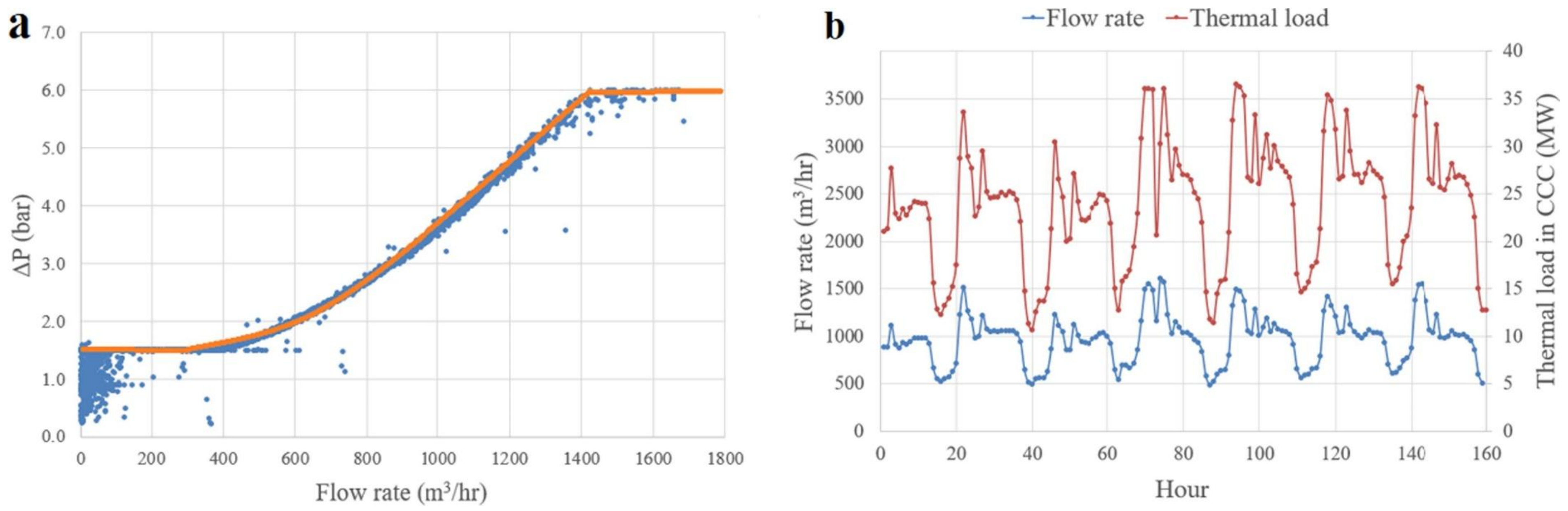
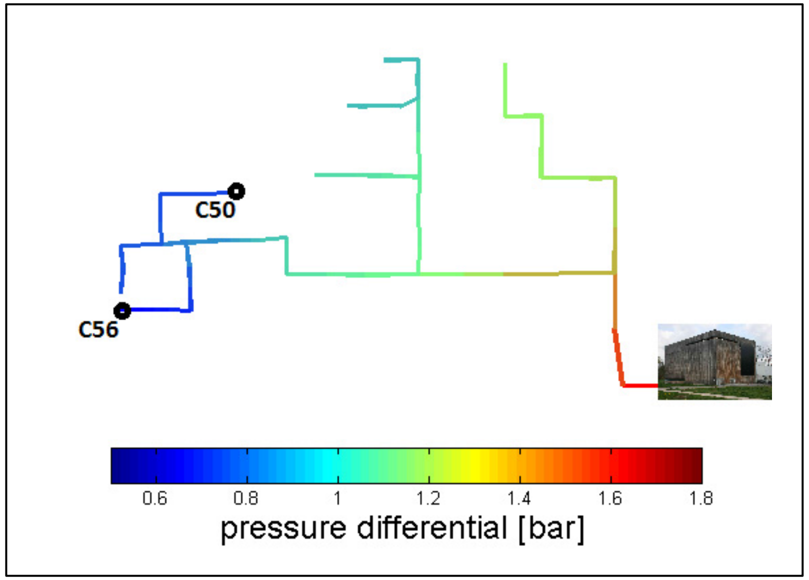


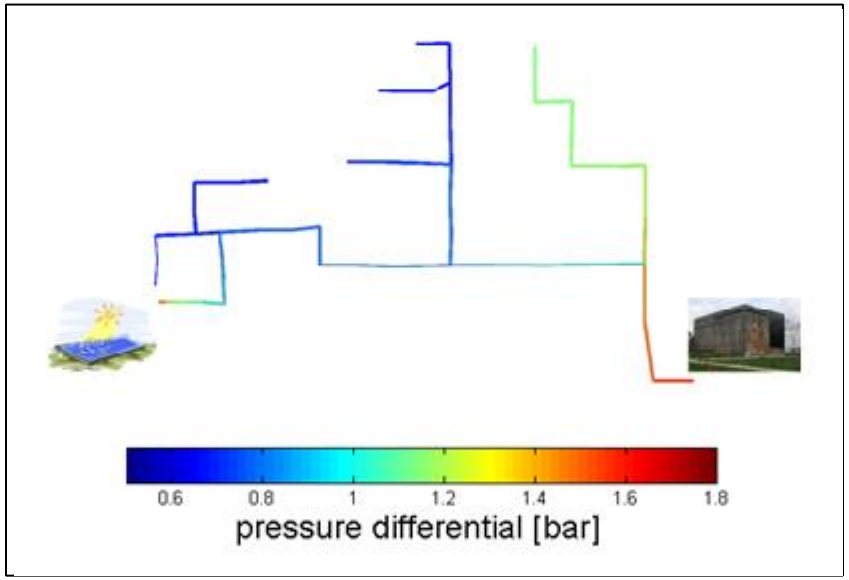
System operation

Heat supply station

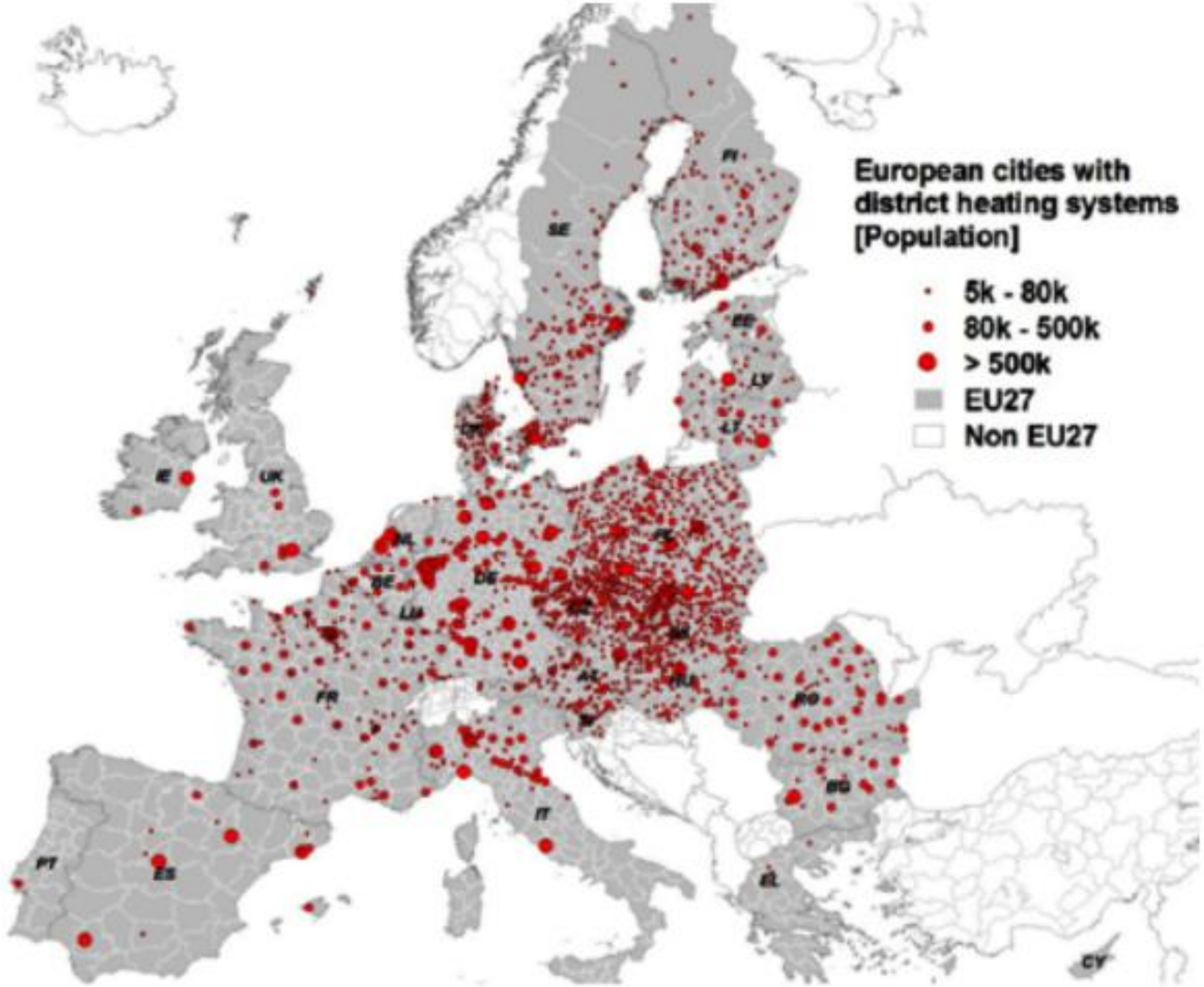
Position of additional heat supply stations

[Source: *Ben Hassine I, Eicker U, 2014*]



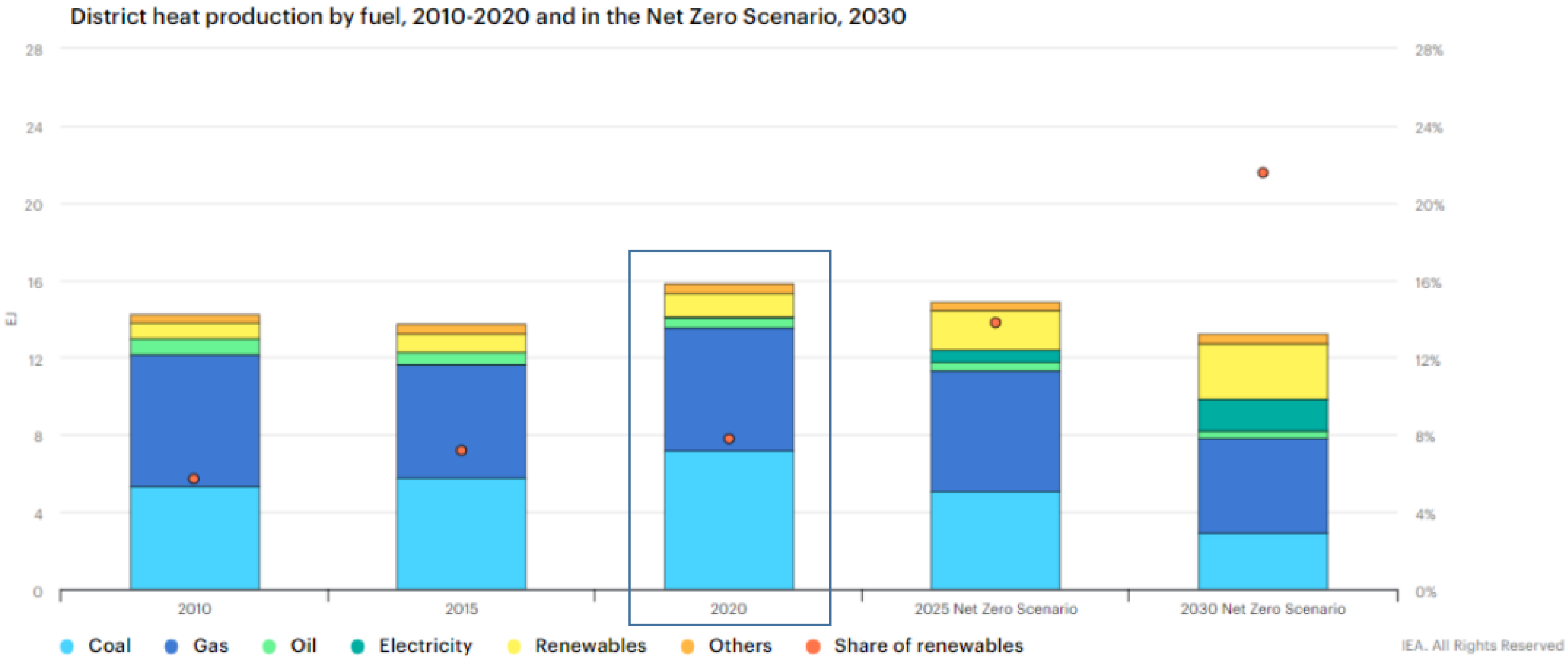


DHC systems in Europe

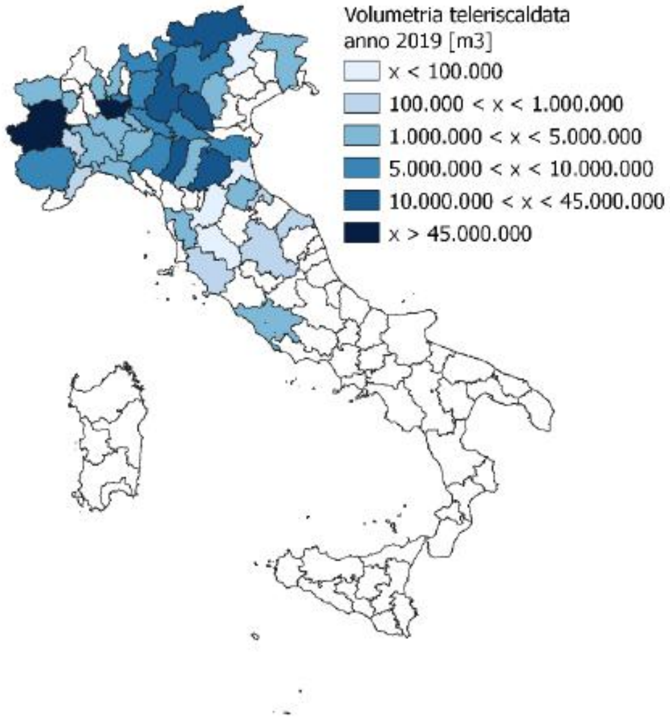


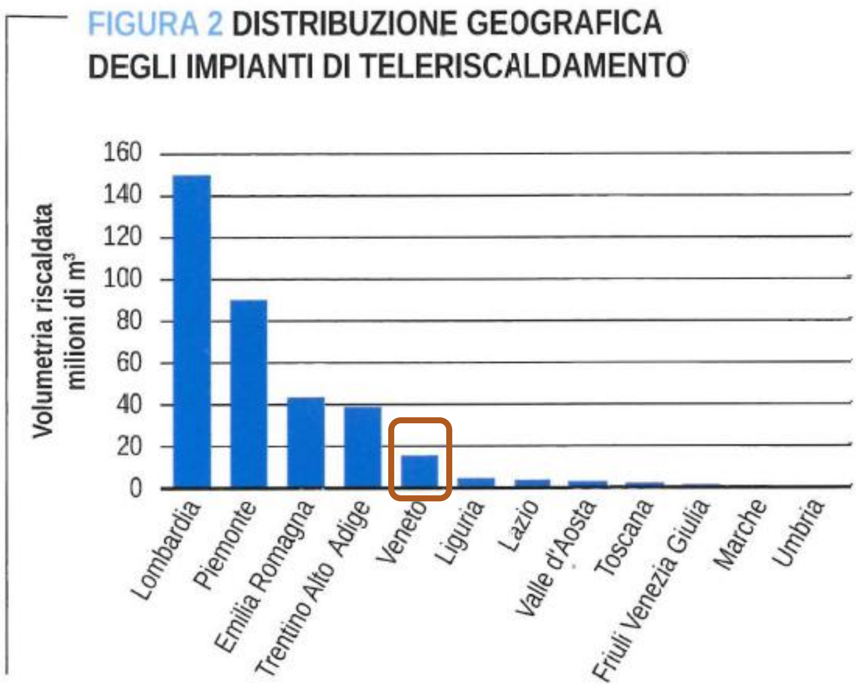
DHC systems in Europe

Heat supply mix



DHC systems in Italy





ONLY 2.3% OF THE ITALIAN HEAT DEMAND SUPPLIED BY DH !

[Fonte: *Annuario AIRU 2020*]

DHC systems in Italy

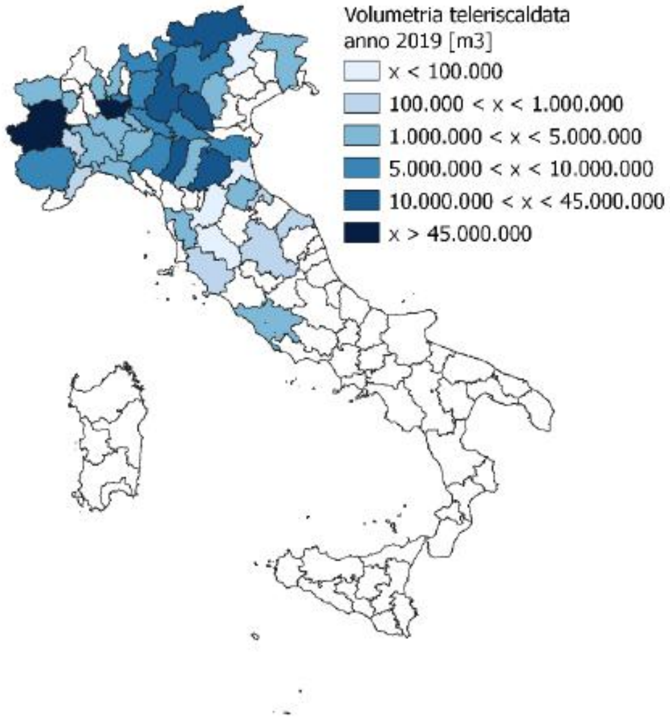
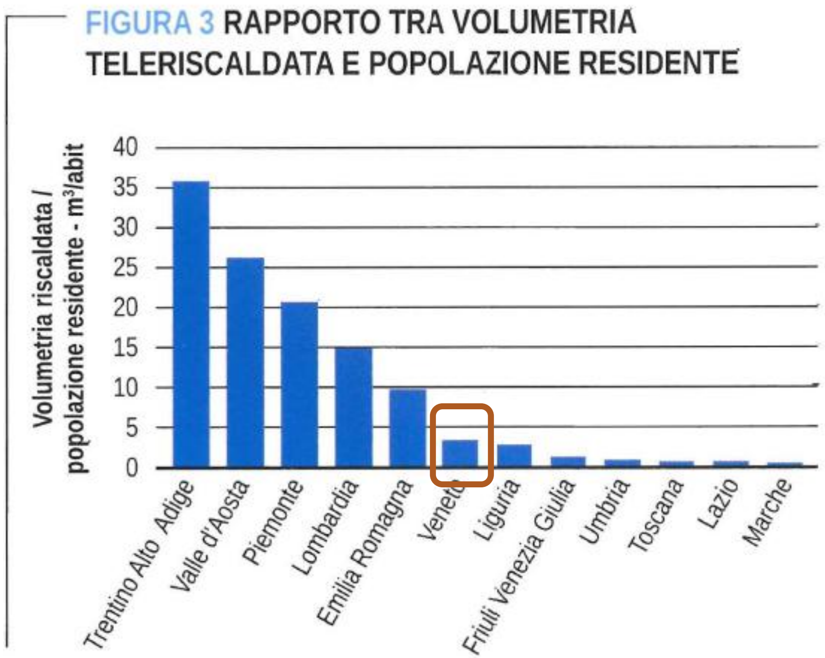


Figura 1.5 Volumetria teleriscaldata nell'anno



[Fonte: *Annuario AIRU 2020*]

The environmental challenge

Decarbonization of existing DHC systems

To reduce the share of fossil fuels in the heat supply mix of the **existing networks** there are clear steps to be undertaken:

1) Reduction of operating temperatures (90-60°C → 70-40°C)
2) Integration of renewables (e.g. solar thermal, ground and air-source heat pumps etc) and industrial waste heat
3) Integration of seasonal thermal storage systems
4) Monitoring substations and improve system control

The environmental challenge

Decarbonization of existing DHC systems

Today’s situation: -25% primary energy consumption compared to replaced individual systems

FIGURA 2 Tecnologia di produzione dell’energia immessa in rete – anno 2020

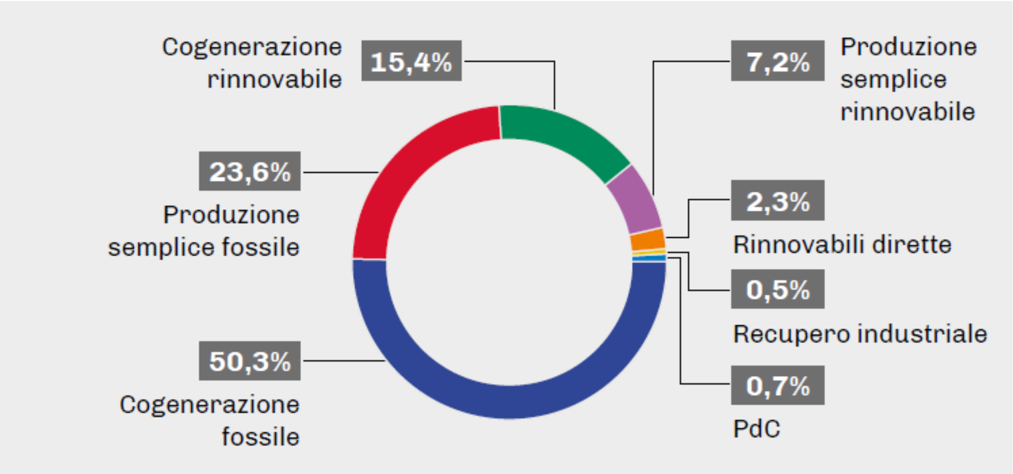
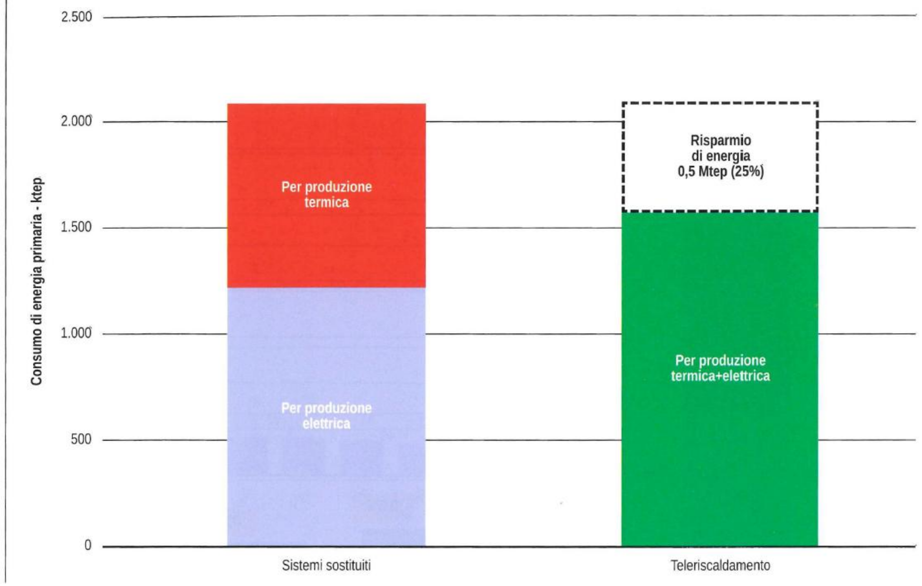


FIGURA 14 RISPARMIO DI ENERGIA PRIMARIA FOSSILE CONSEGUITO DALLE RETI DI TELERISCALDAMENTO



The environmental challenge

Decarbonization of existing DHC systems

Today's situation: -30% CO_2 emissions compared to replaced individual systems

FIGURA 2 Tecnologia di produzione dell'energia immessa in rete – anno 2020

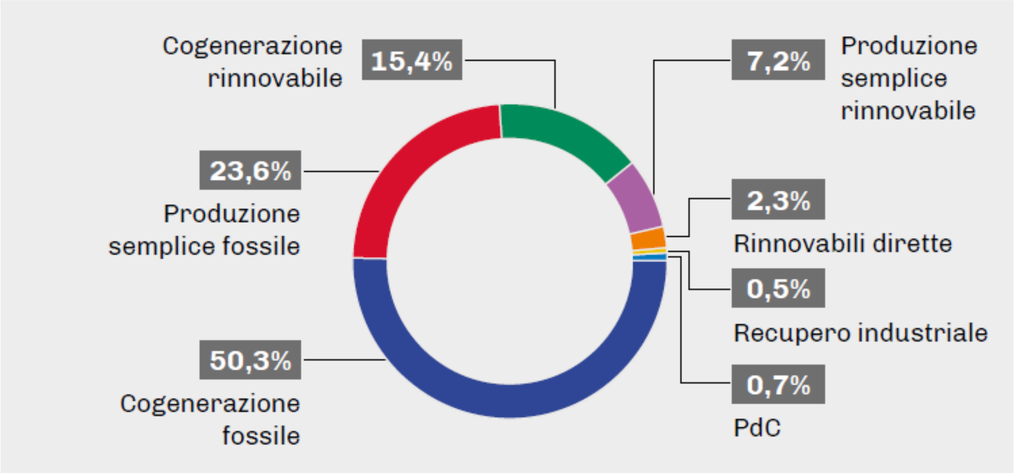
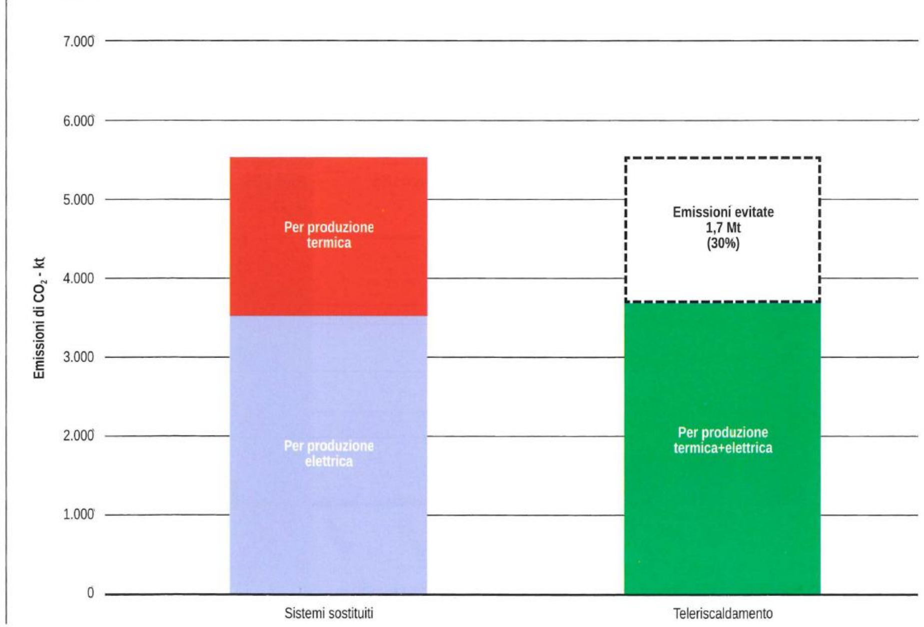
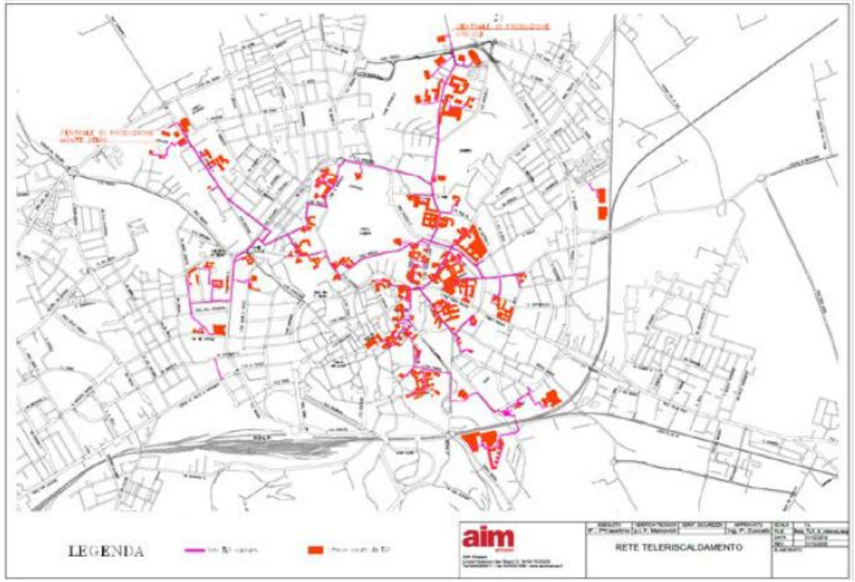


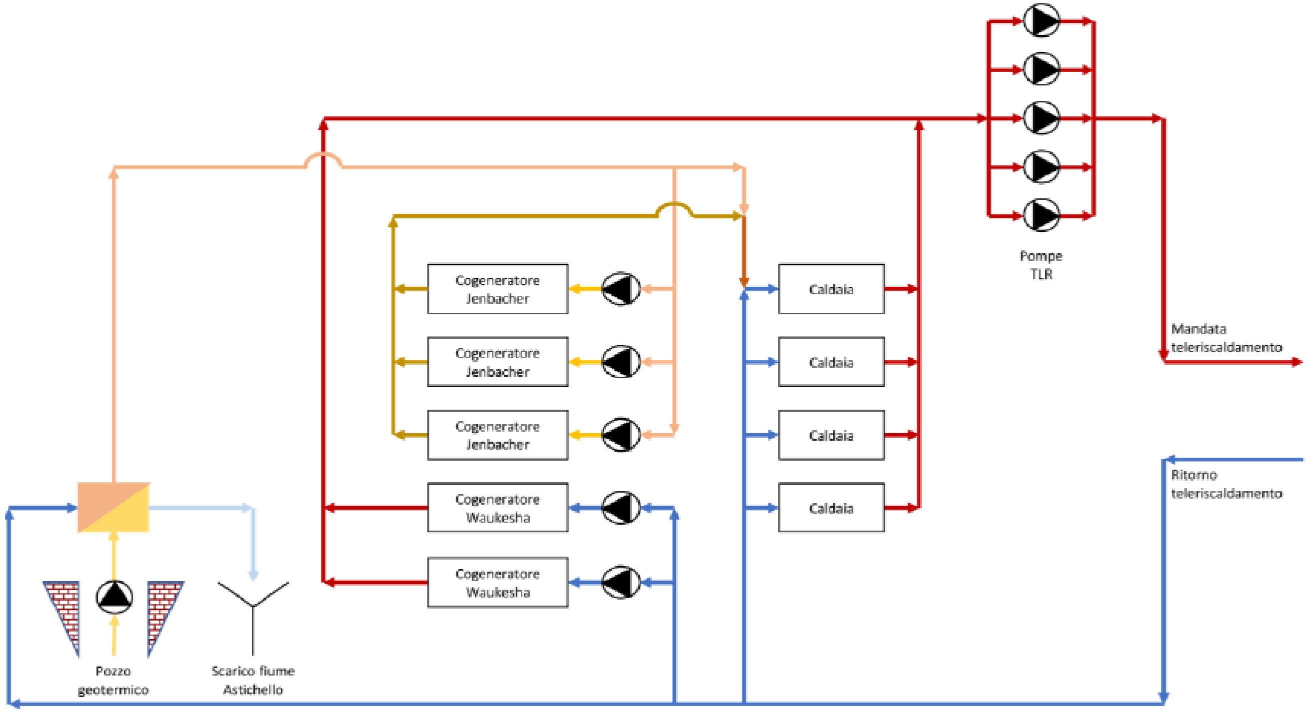
FIGURA 15 BILANCIO DELLE EMISSIONI DI CO_2 DEI SISTEMI DI TELERISCALDAMENTO



The environmental challenge

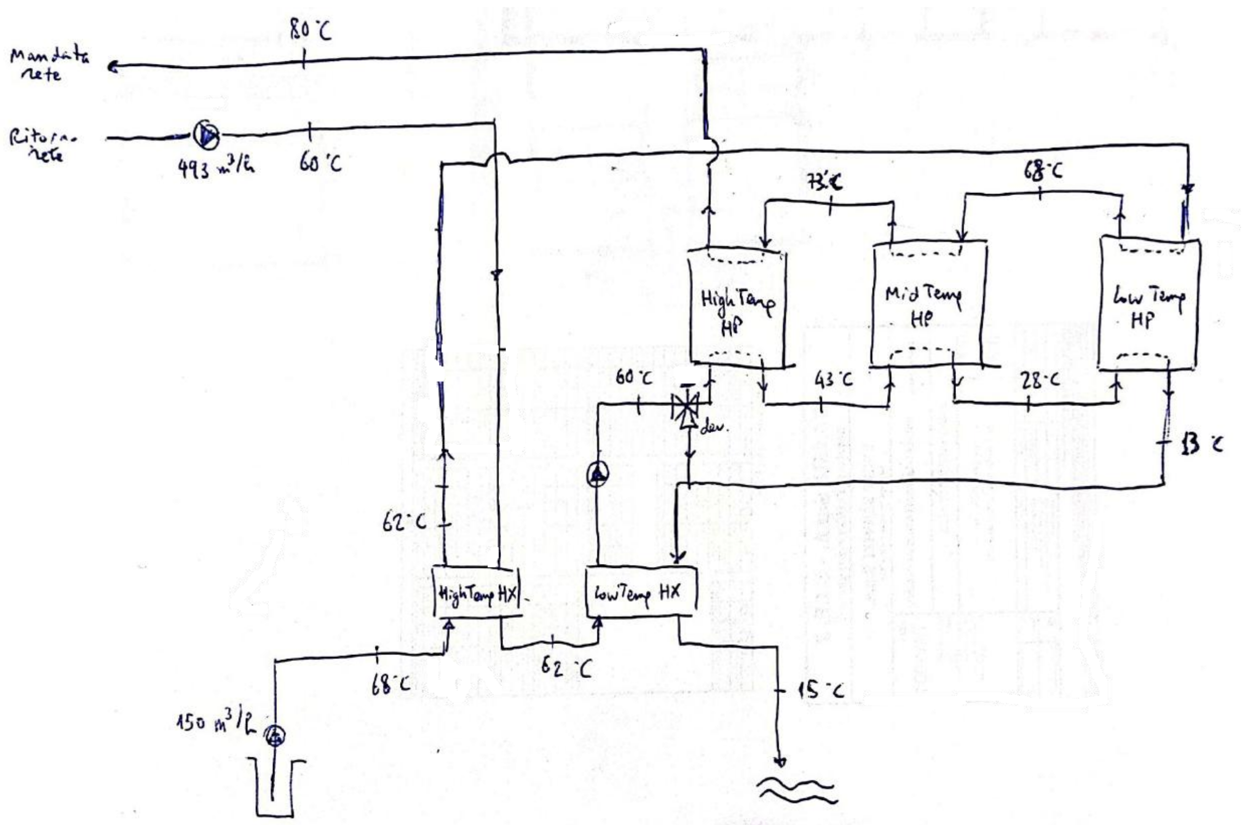
Case study: Vicenza





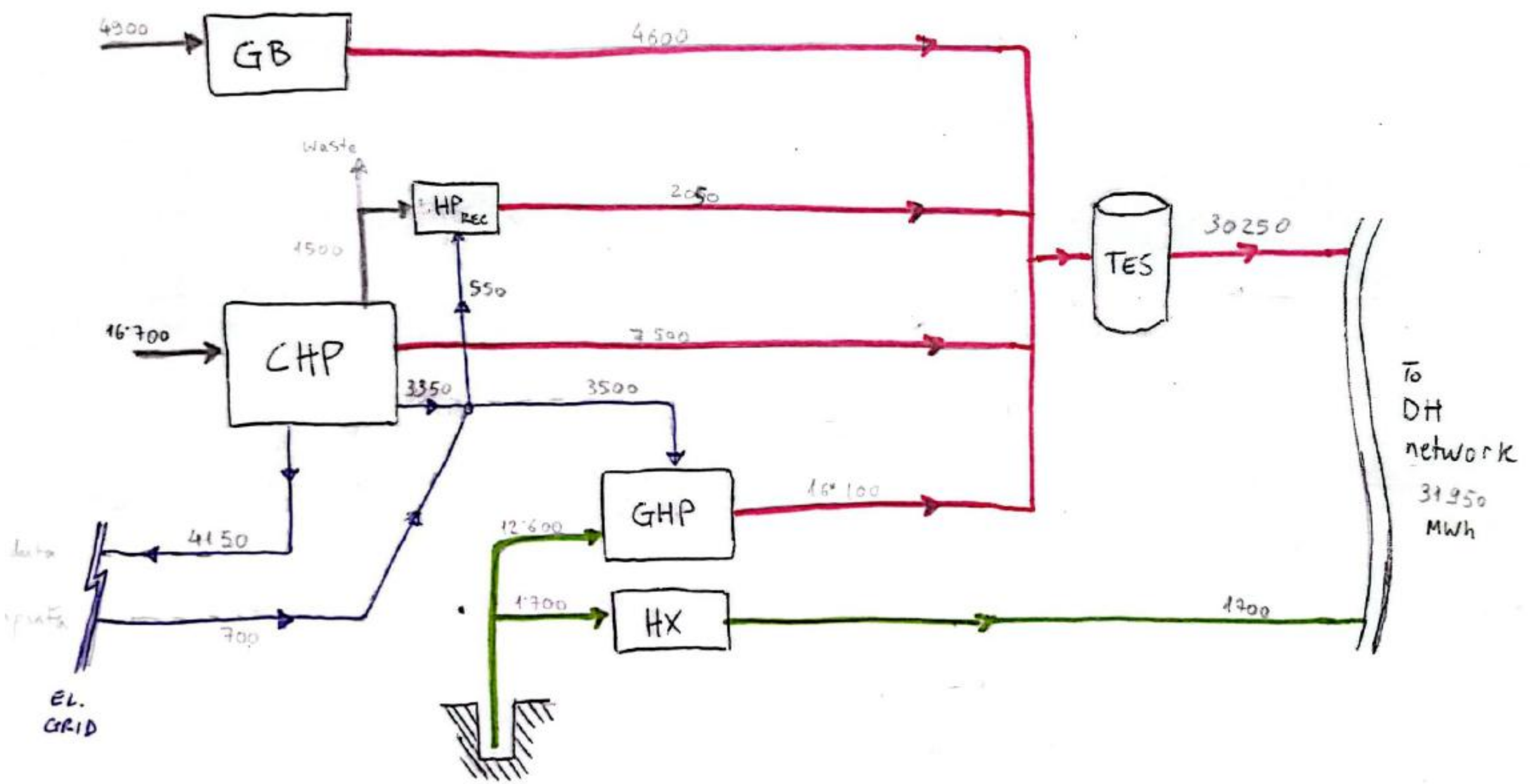
The environmental challenge

Case study: Vicenza



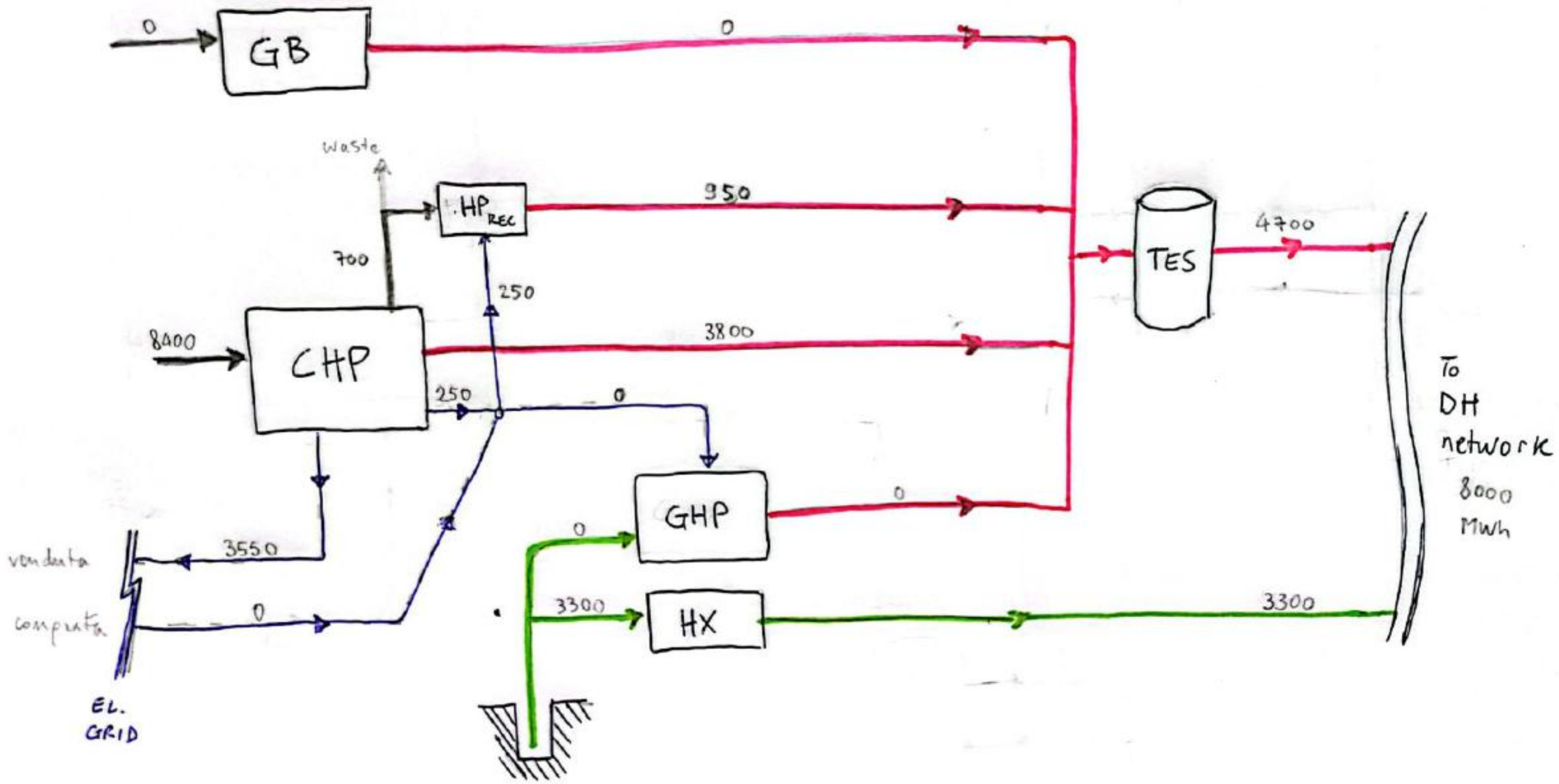
The environmental challenge

Case study: Vicenza



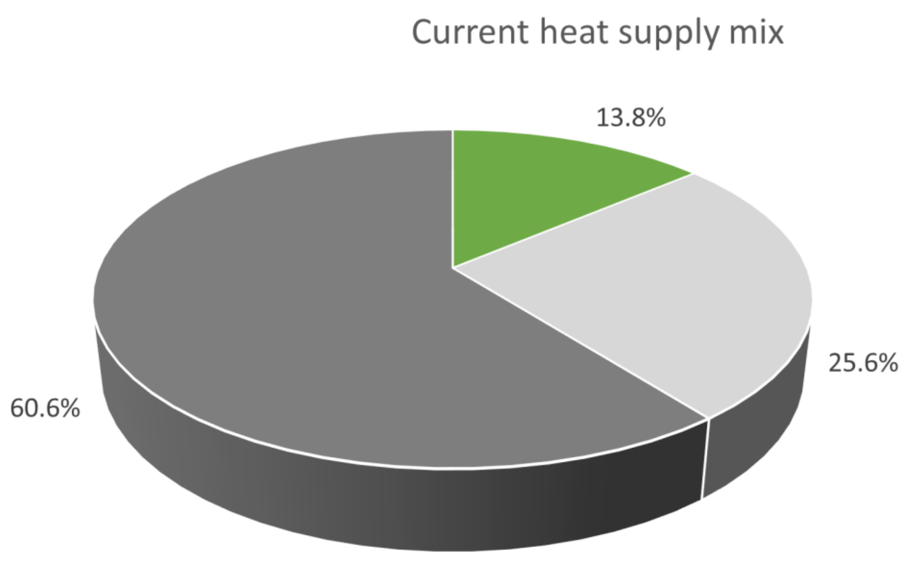
The environmental challenge

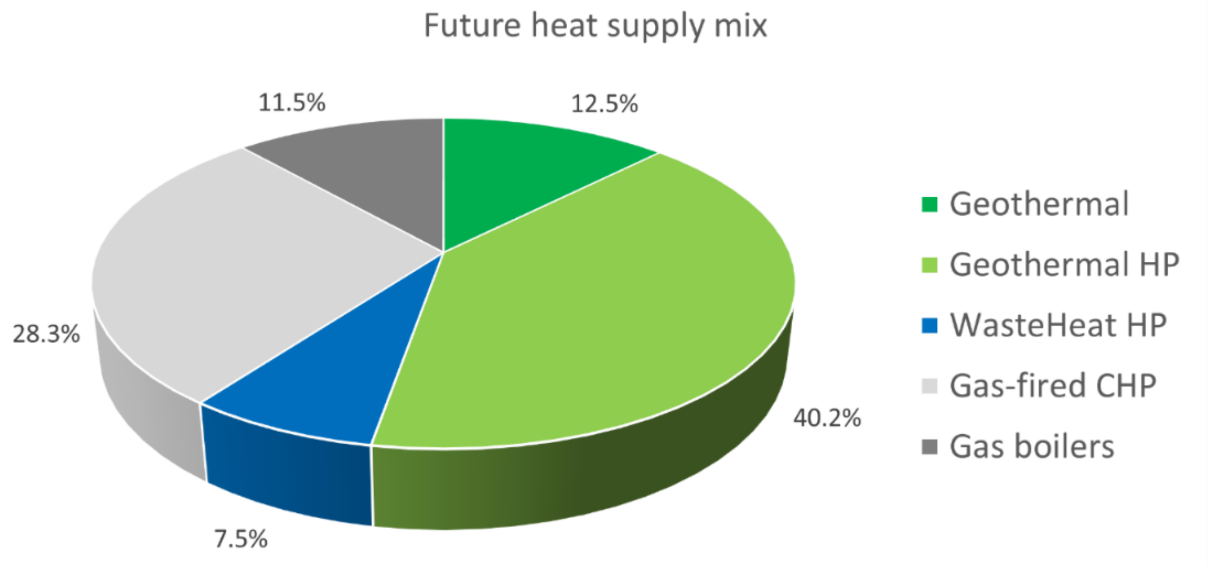
Case study: Vicenza



The environmental challenge

Case study: Vicenza





The environmental challenge

Seasonal thermal storage

Storage type	Storage medium	Volumetric heat capacity [MJ/(m3 K)]	Latent heat [kJ/kg]	Density [kg/m3]	Energy density [kWh/m3]
Latent	Salt hydrate Tf = 25°C		125.9	1800	63.0
	Salt hydrate Tf = 29°C		188.0	1562	81.6
	Salt hydrate Tf = 34°C		246.0	1442	98.5
	Ice/Water	4.18	334.0	1000.0	92.8
Sensible	Water (deltaT = 10 K)	4.18			11.6
	Water (deltaT = 20 K)	4.18			23.2
	Water (deltaT = 50 K)	4.18			58.1
	Ground (deltaT = 10 K)	2.40			6.7
	Ground (deltaT = 20 K)	2.40			13.3

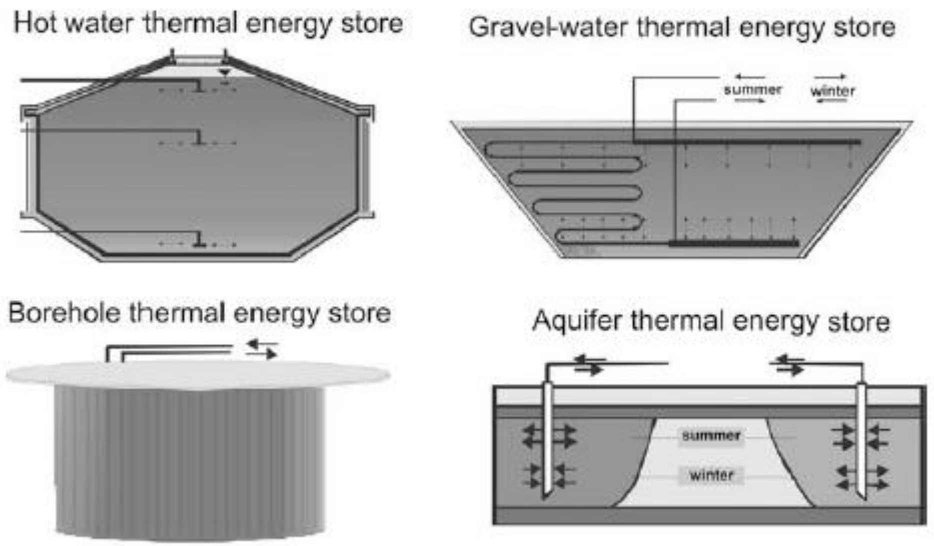
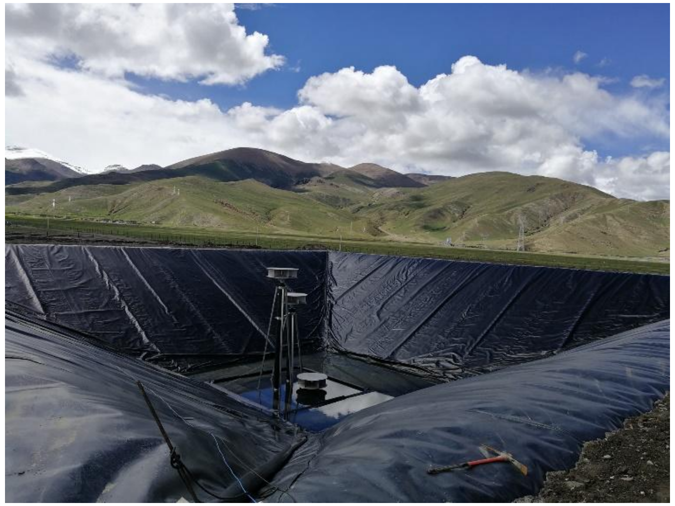


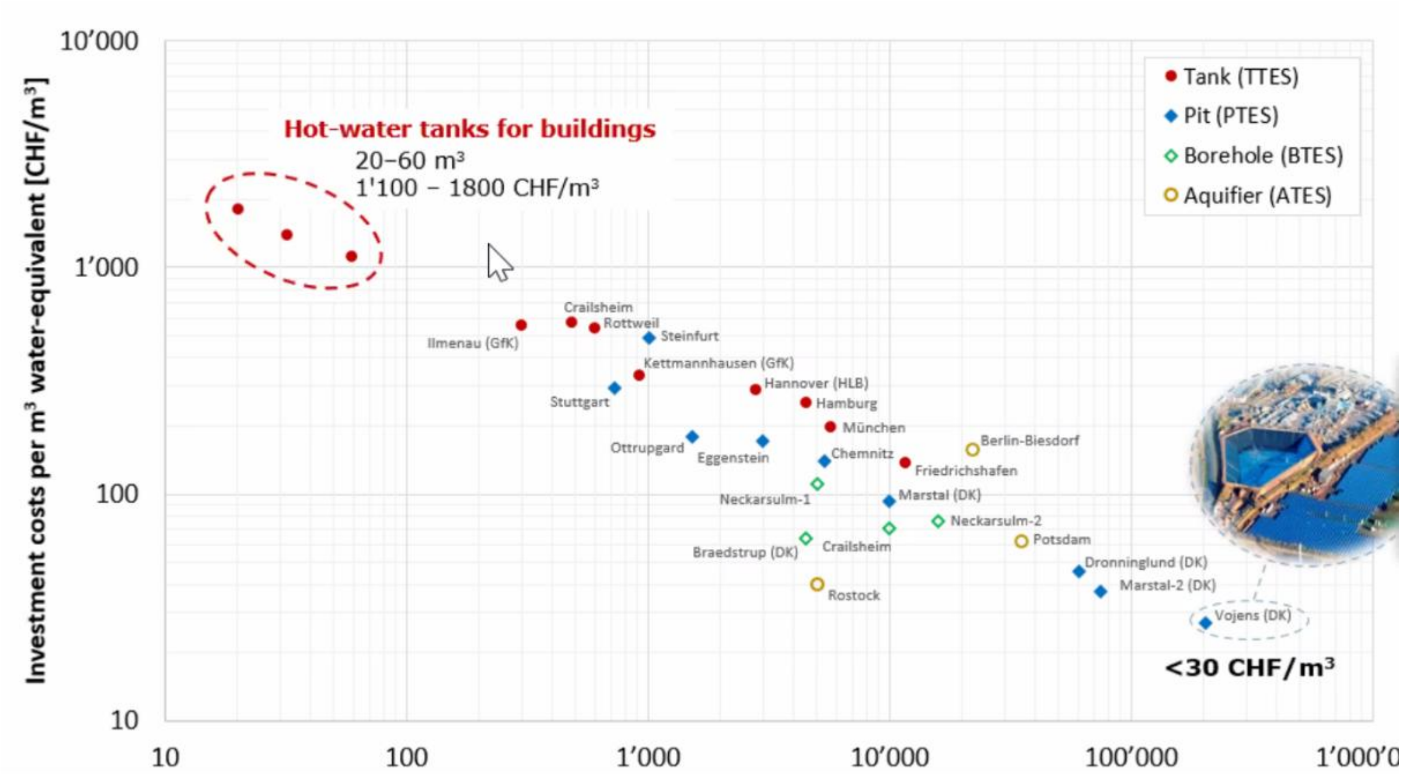
Fig. 2. Types of seasonal thermal energy stores (Benner et al., 2003).

The environmental challenge

Seasonal thermal storage

Economies of scale





The environmental challenge

Example: 5th generation with seasonal thermal storage

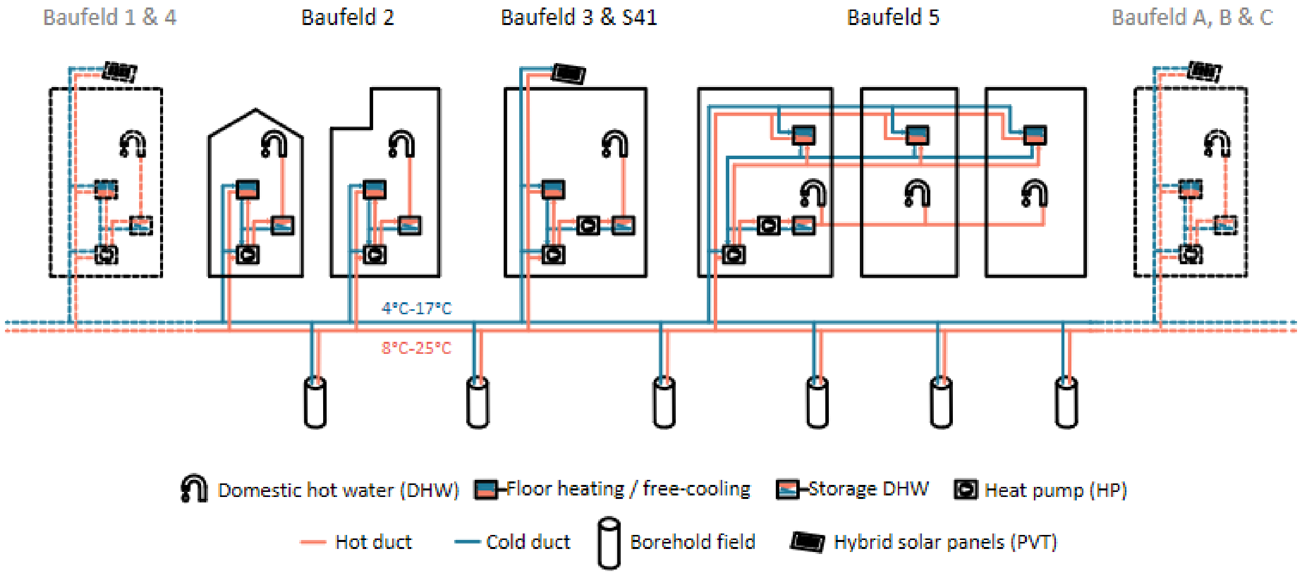


Fig. 1. Scheme of LTN Suurstoffi

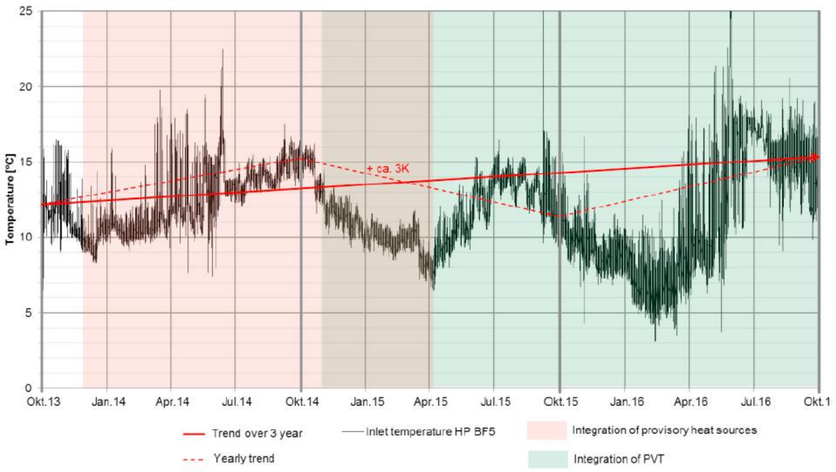


Fig. 3. Network temperature over three years

[Source: *Vetterli et al, 2017*]