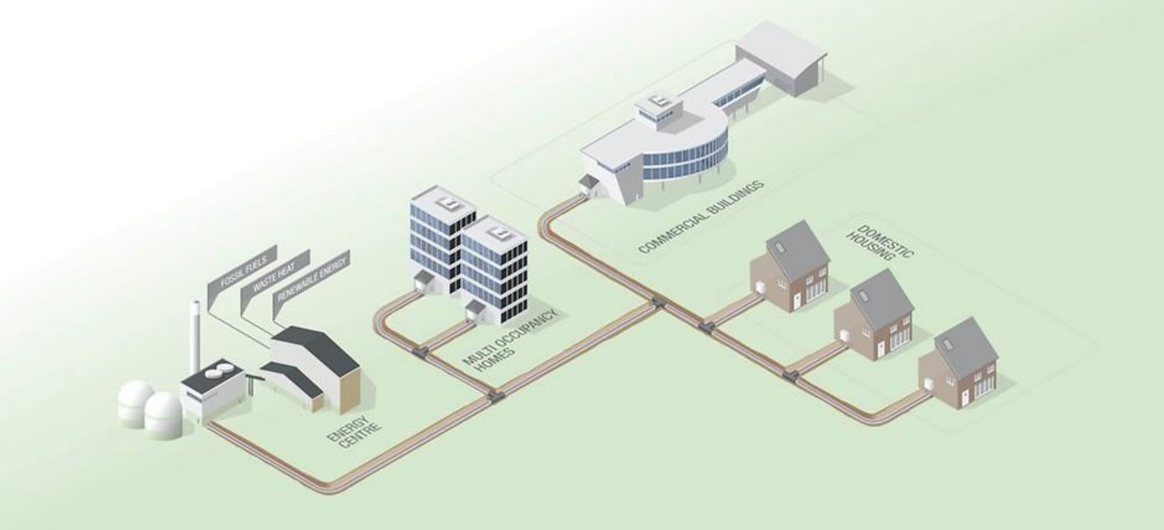
# District heating and cooling systems

HEATING VENTILATION AIR CONDITIONING SYSTEMS
31-05-2023
Jacopo Vivian

# What is it?

**Characteristics**



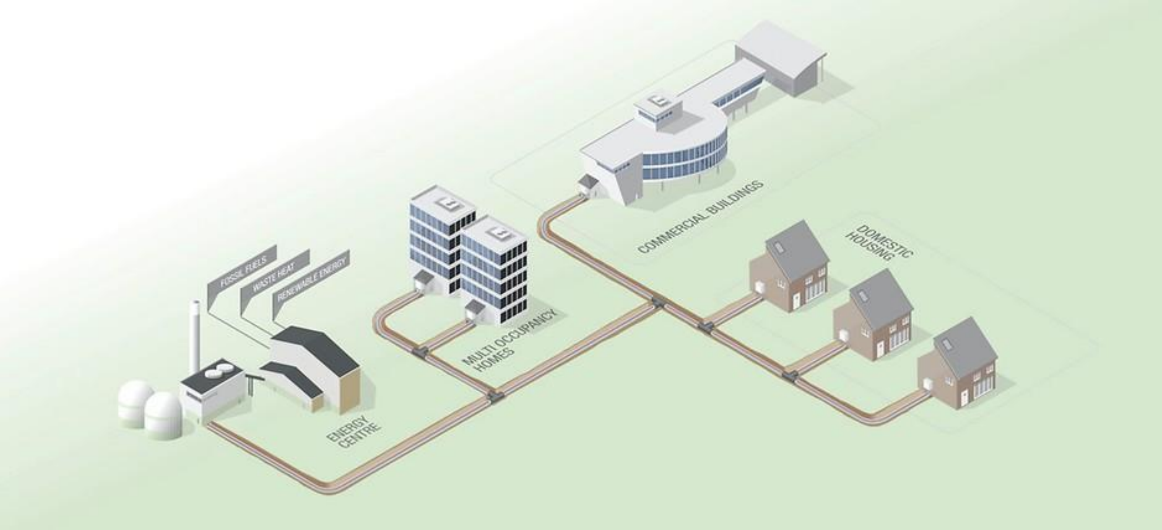
[Source: *https://www.rehau.com/*]

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**

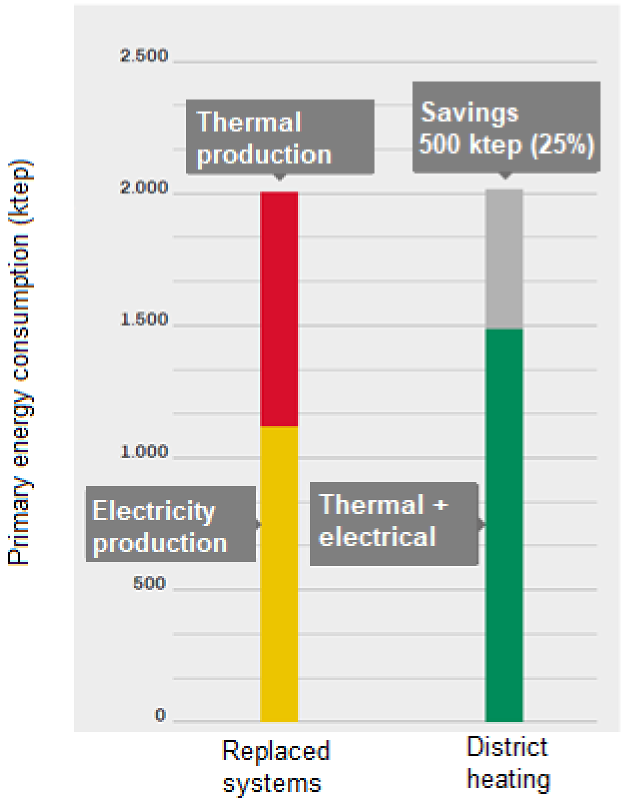
1) Supply station(s)
2) Distribution system
3) Substations

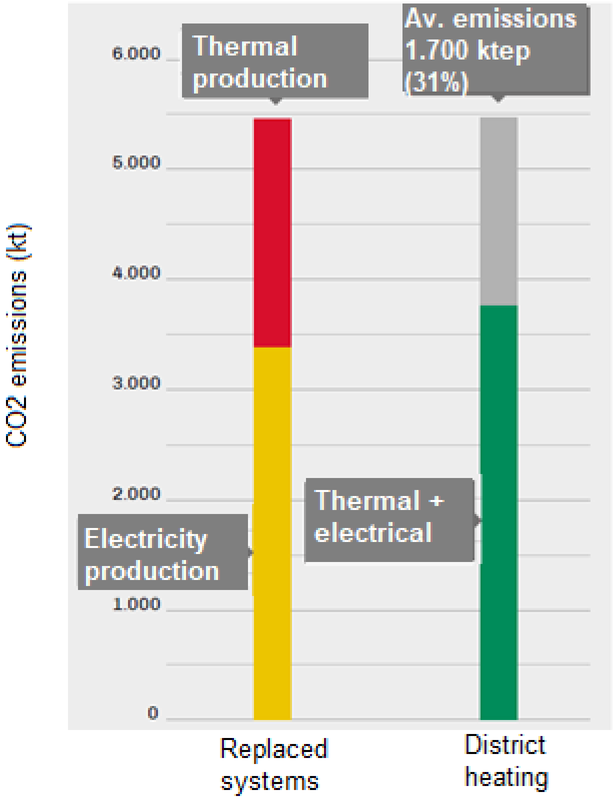


[Source: *https://www.rehau.com/*]

# Why do we need DH?

## Advantage





[Source: *Annuario AIRU 2021*]

# Who are the typical users?

**FIGURA 4** **Volumetria teleriscaldata distinta per tipologia d'utenza**

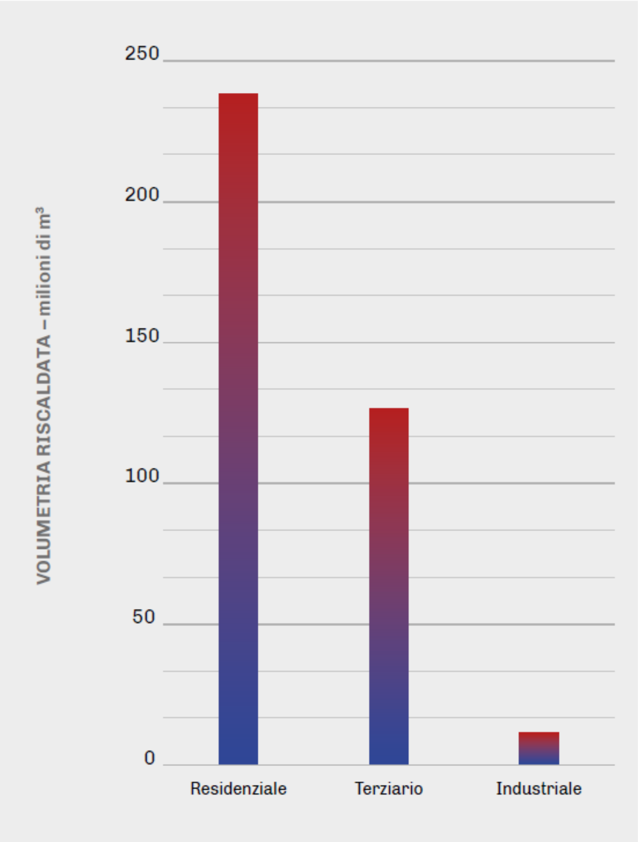
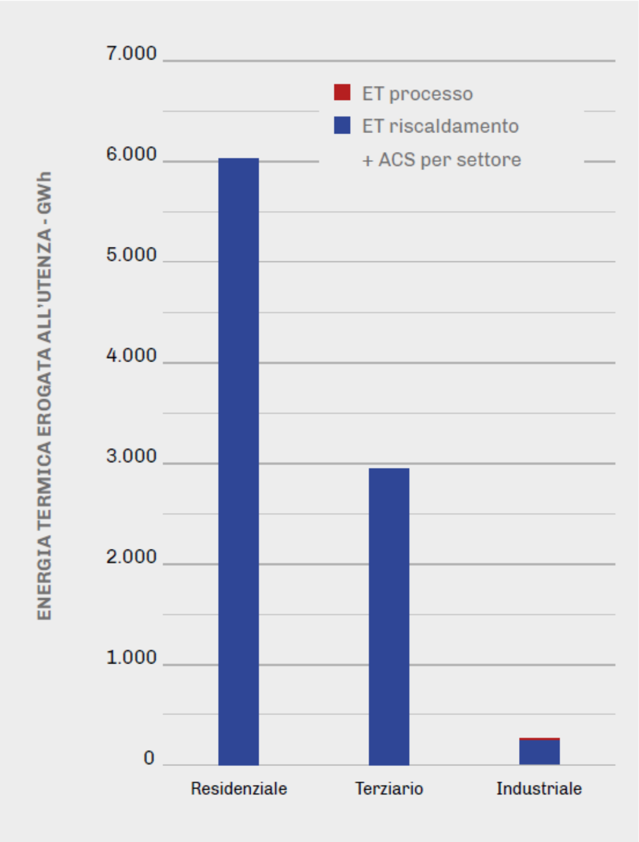


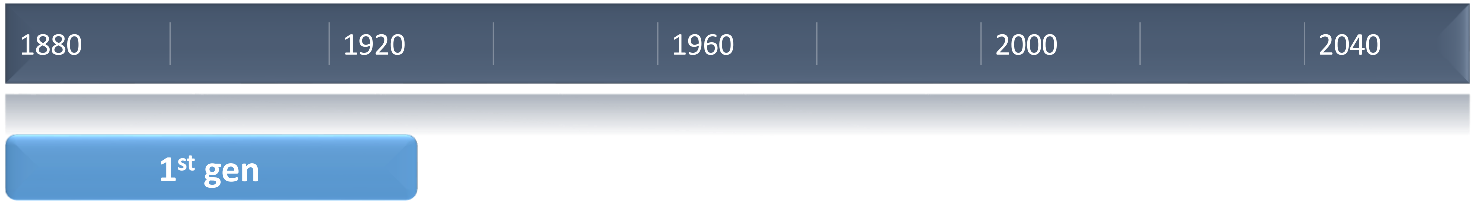
**FIGURA 5** **Energia termica erogata distinta per tipologia d'utenza**



[Source: *Annuario AIRU 2021*]

# A bit of history

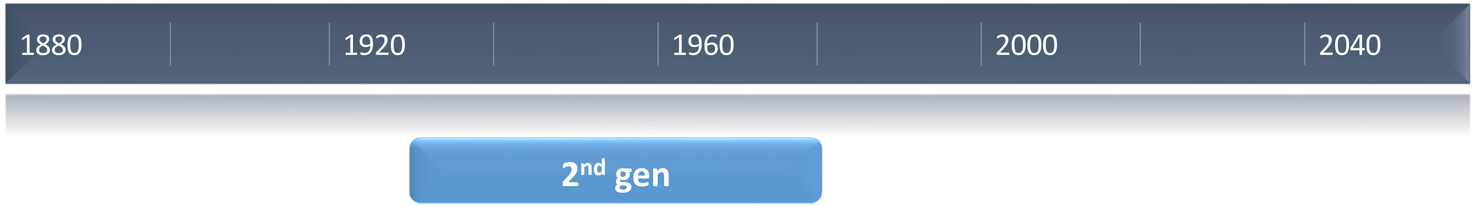
## First generation



**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

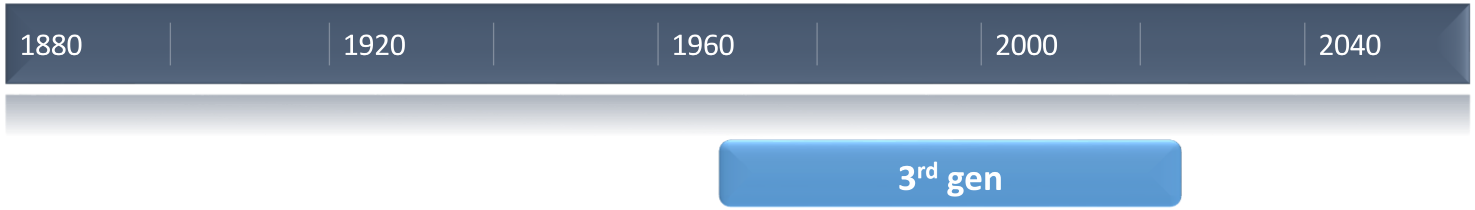


**Where:** URSS
**Why**: Planned economy
**Heat carrier fluid:**
Superheated water (>100°C)
**Characteristics**:
Oversized pipes with no thermal insulation
«Production-driven» regulation

Constantlearner www.delcampe.net

# A bit of history

## Third generation



1880 1920 1960 2000 2040

3rd gen

**Where:** Scandinavian countries

**Why**: Efficiency and energy security concerns

**Heat carrier fluid:**

Hot water (90/60°C)

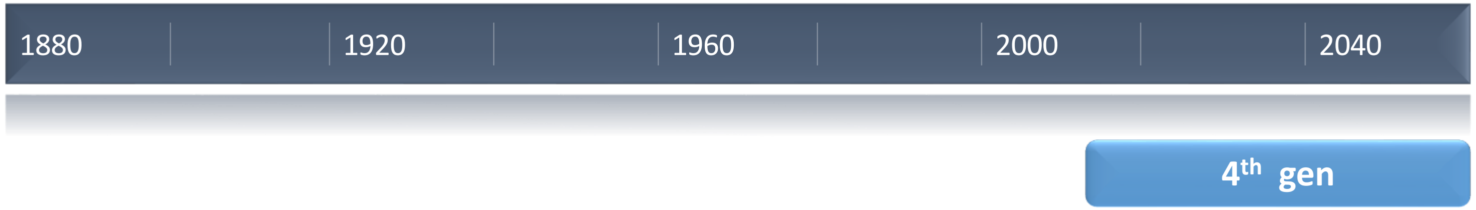
**Characteristics:**

Pre-insulated pipes

«Demand-driven» regulation

# A bit of history

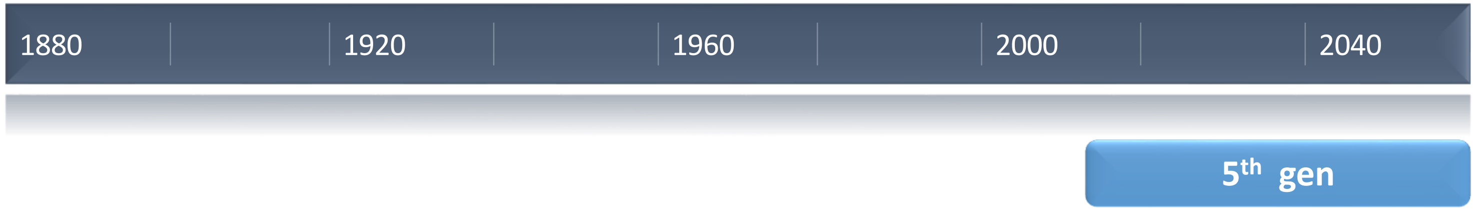
## Fourth generation



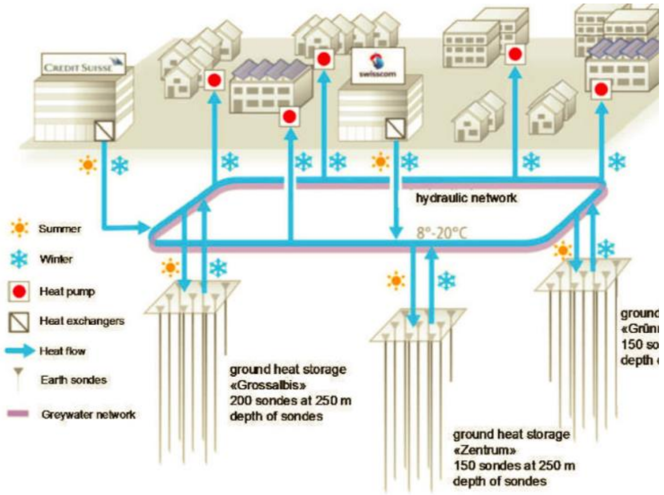
**Where:** Scandinavian countries
**Why**: Heat demand reduction, renewables
**Heat carrier fluid:**
Hot water (70/40°C)
**Characteristics:**
Increased supply from renewable heat,
use of twin pipes
«Demand-driven» regulation

# A bit of history

## Fifth generation



**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



# Economic feasibility

**Linear heat density**

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

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

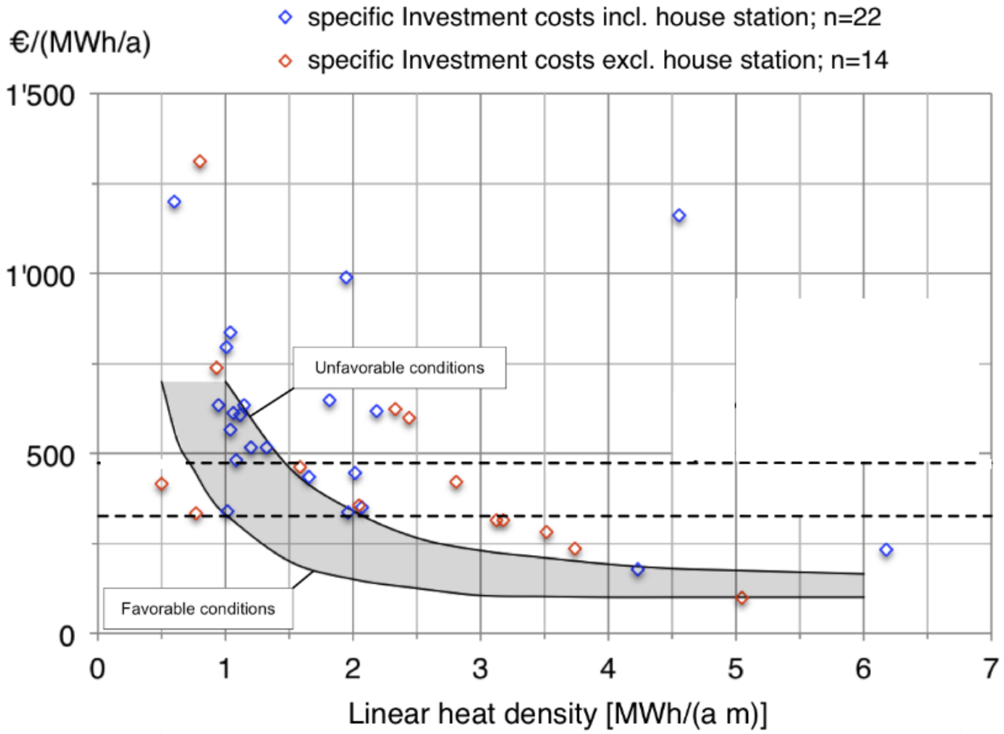
| | Energy delivered to the buildings (MWh) | Overall network length (km) | Linear heat density (MWh/m) |
|---|---|---|---|
| Asiago | 9’711 | 13.47 | 0.72 |
| Brescia DH | 981’194 | 379.8 | 2.58 |
| Brescia DC | 32’122 | 7.91 | 4.06 |
| Ferrara | 134’816 | 82.58 | 1.63 |
| Forni di Sopra | 1’614 | 3.08 | 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

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



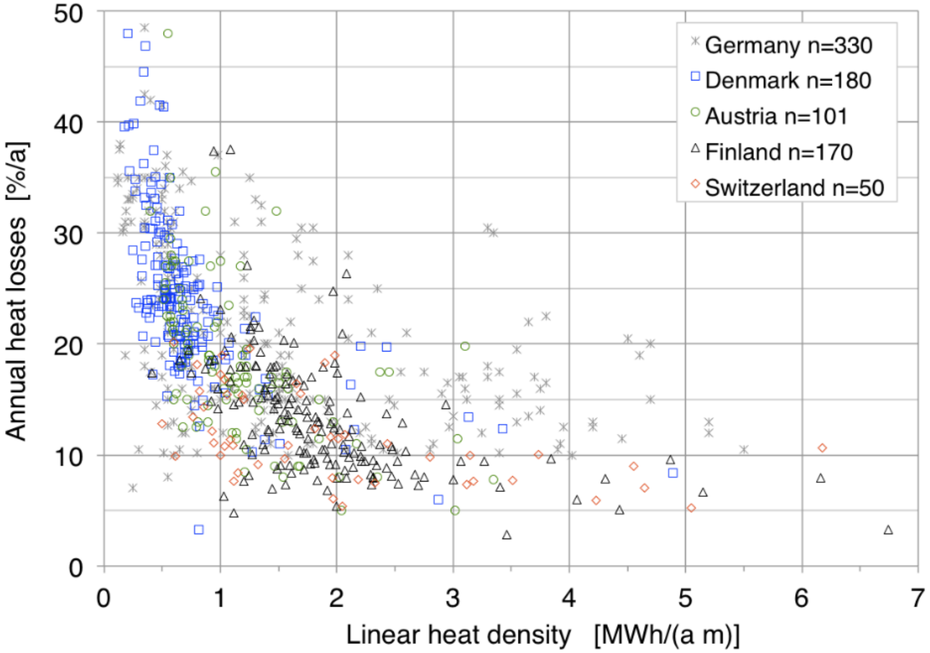
[Fonte: *Status Report on District Heating Systems in IEA Countries, 2014*]

# Economic feasibility

**Linear heat density**

Ratio between annual heat demand and length of the pipes

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

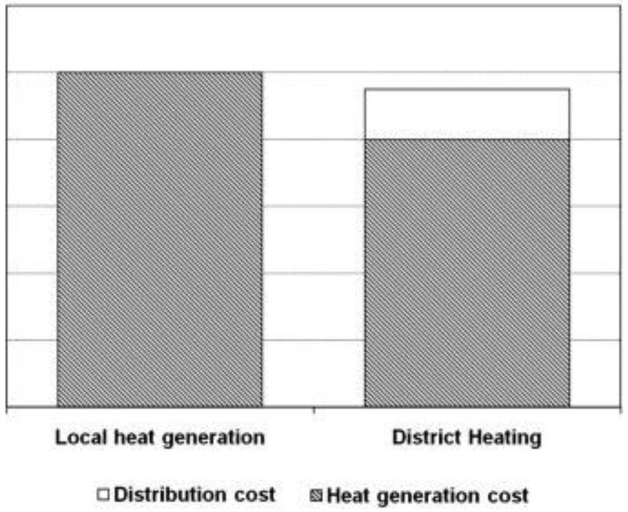


[Fonte: *Status Report on District Heating Systems in IEA Countries, 2014*]

# Economic feasibility

**Distribution network**

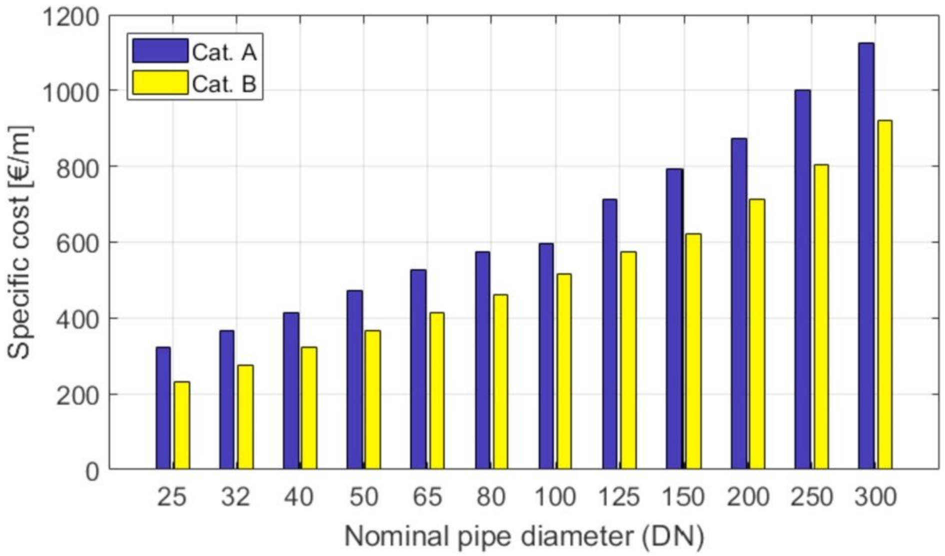
Heat tariff (€/MWh) for the final user must be the same (or lower) than that of alternative individual heat supply solutions (e.g. gas boilers). Therefore, heat generation cost for the utility must be lower than that of domestic users.

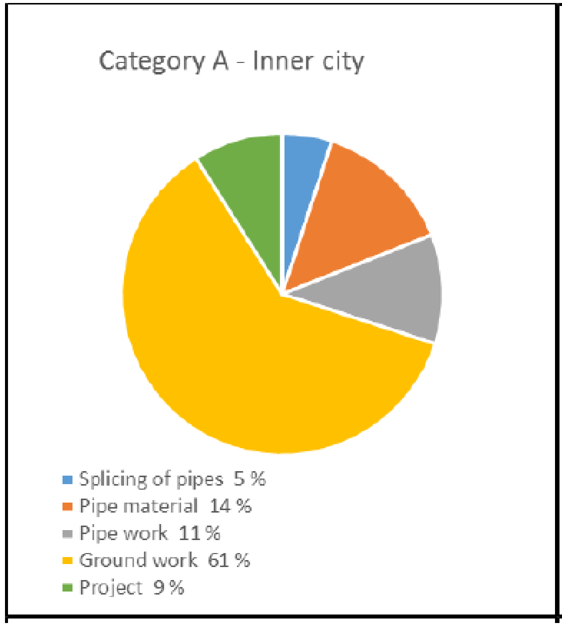


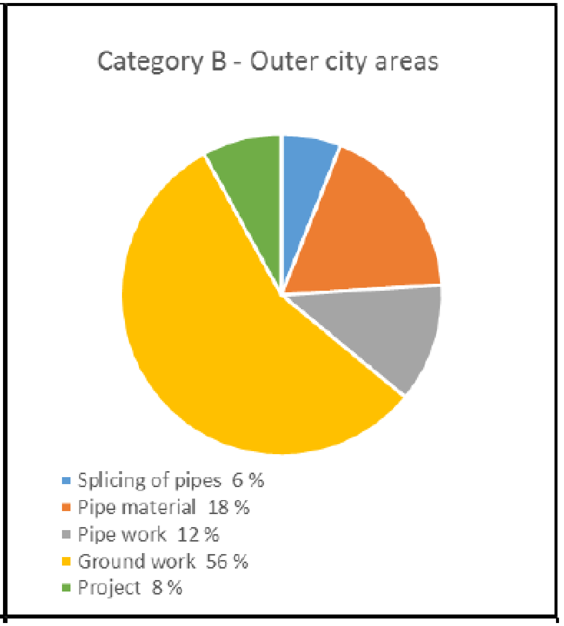
[Fonte: *Persson & Werner, 2011*]

# 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. 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

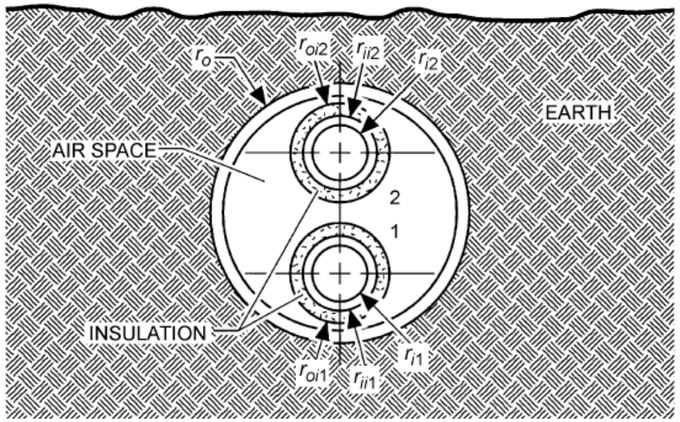
- *Advantages*: High strength and good flexibility, can be joined by welding for a high-integrity joint that can be inspected for quality control, widely available in all sizes, familiar material to most workforces.
- *Disadvantages*: Relatively high cost, highly susceptible to corrosion and will require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

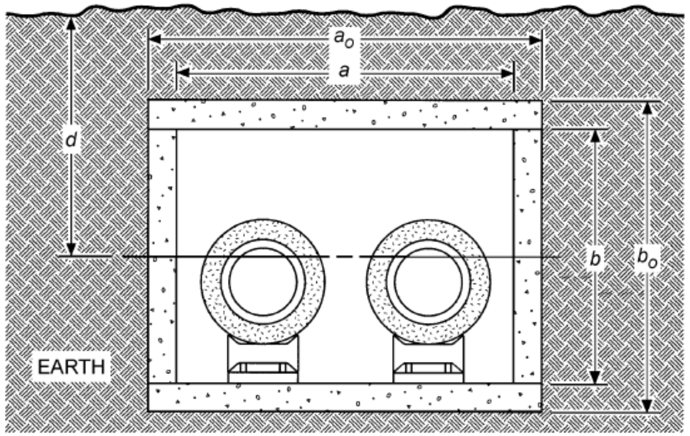
### PE and HDPE

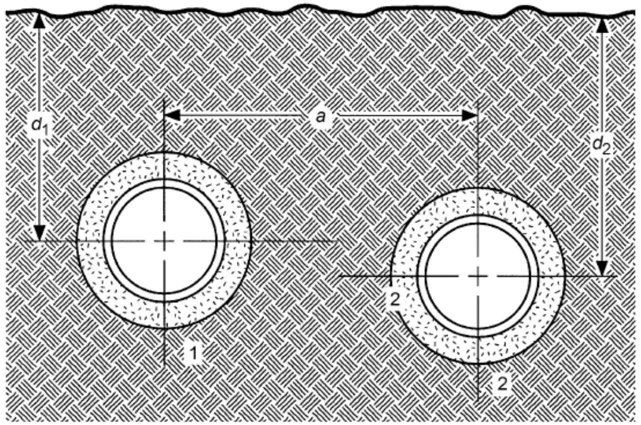
- *Advantages*: Low weight, very flexible, can be fusion welded for high-integrity joints, available in sizes up to 1.6 m. Leak free and fully restrained (no anchor blocks).
- *Disadvantages*: Low strength compared to steel results in significant wall thickness and thus cost in larger diameters. Increased 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







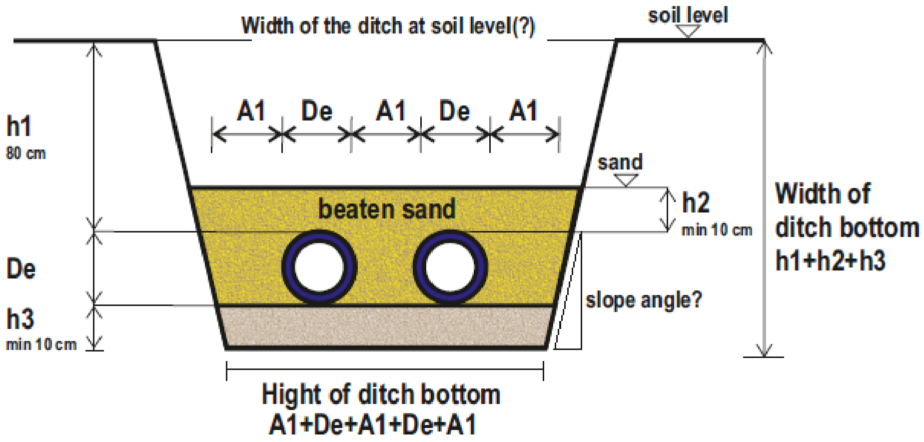
# System design

## 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

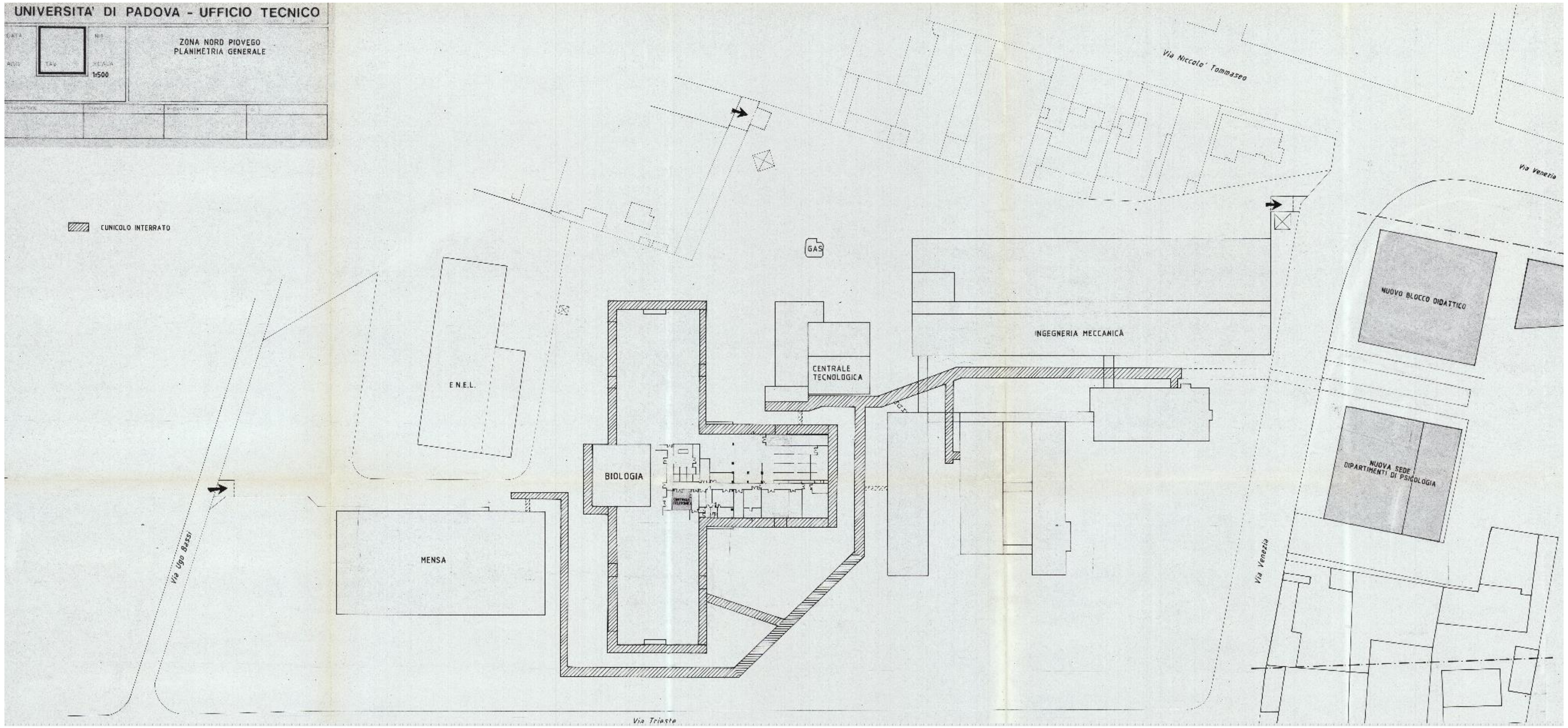
**A1** = minimum distance to install the pipes for processing operations

**De** = outside diameter of the pipes

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

# System design

## Example: Nord Piovego

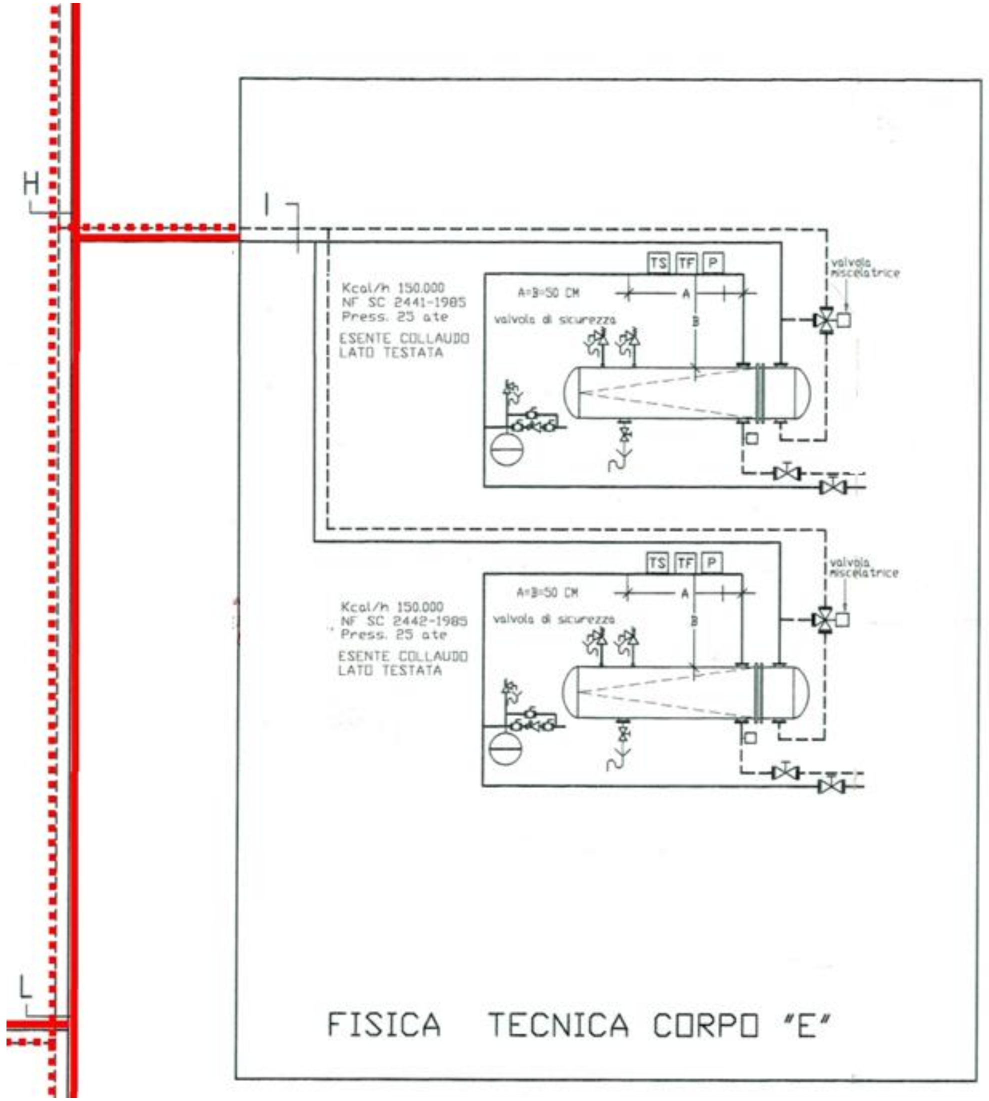


# System design

**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.



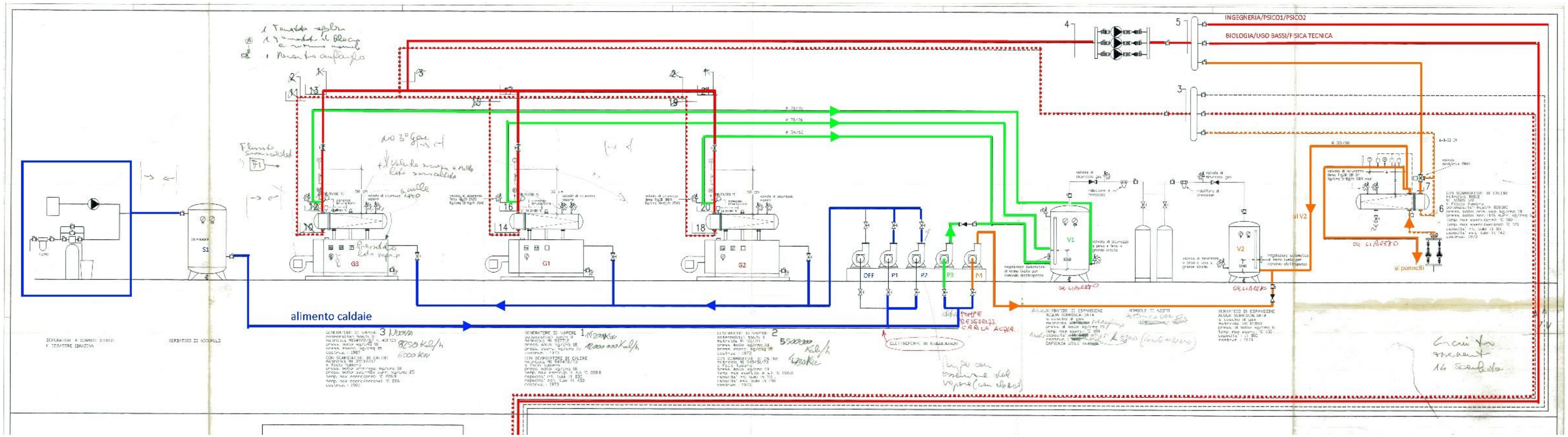
# System design

**Example: Nord Piovego**

Difficult to make efficiency measures on large existing buildings with multiple uses

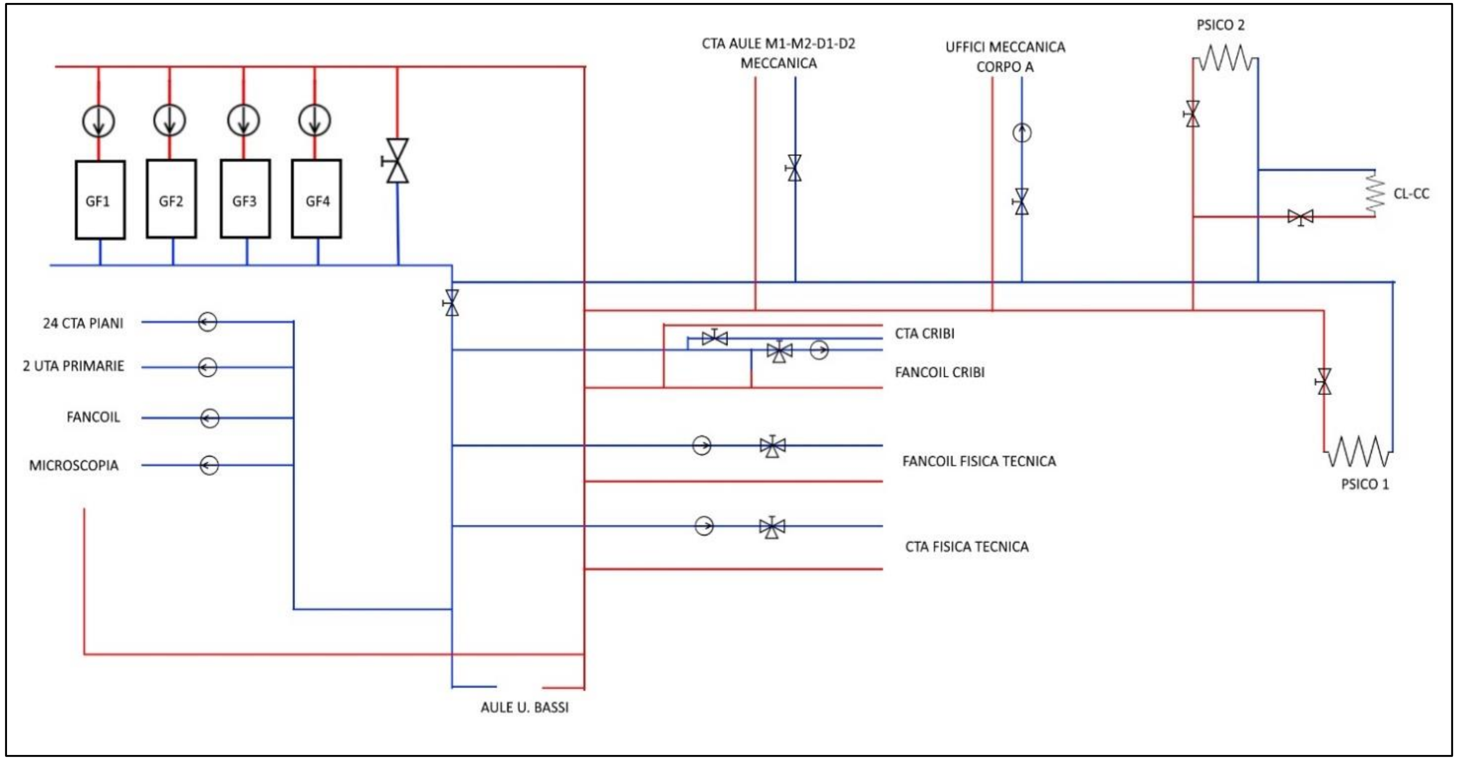
# System design

## Heat supply stations



# System design

## Cooling supply stations



# System operation

**Important characteristics**

**User substations**

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

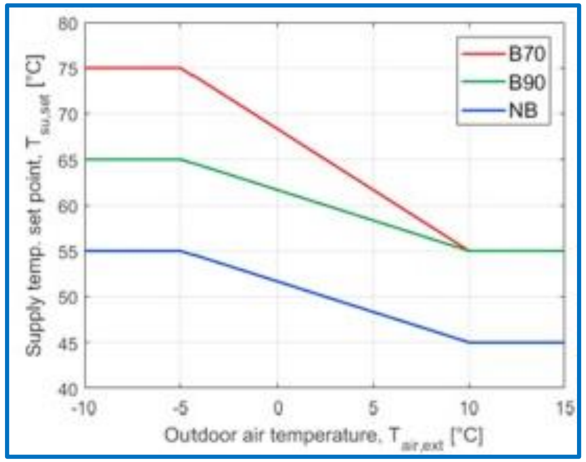
**Heat supply station**

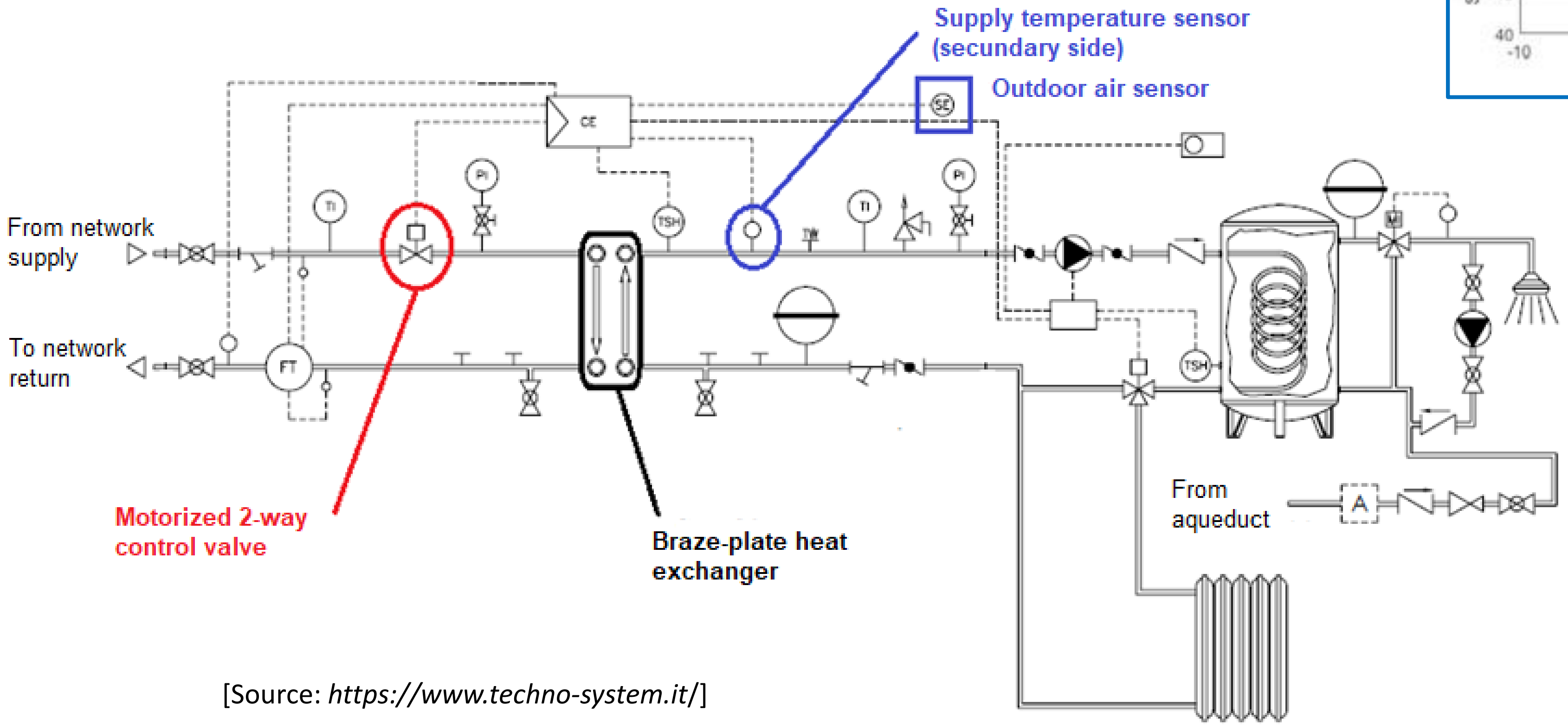
- Constant flow vs variable flow operation

# System operation

## User substations

$$T_e \rightarrow T_{su,set}$$

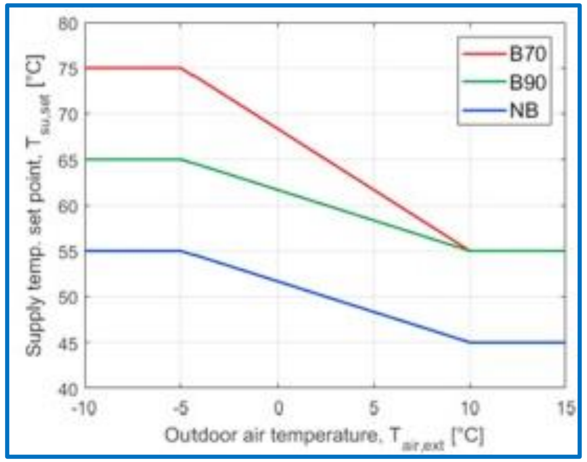




[Source: *https://www.techno-system.it/*]

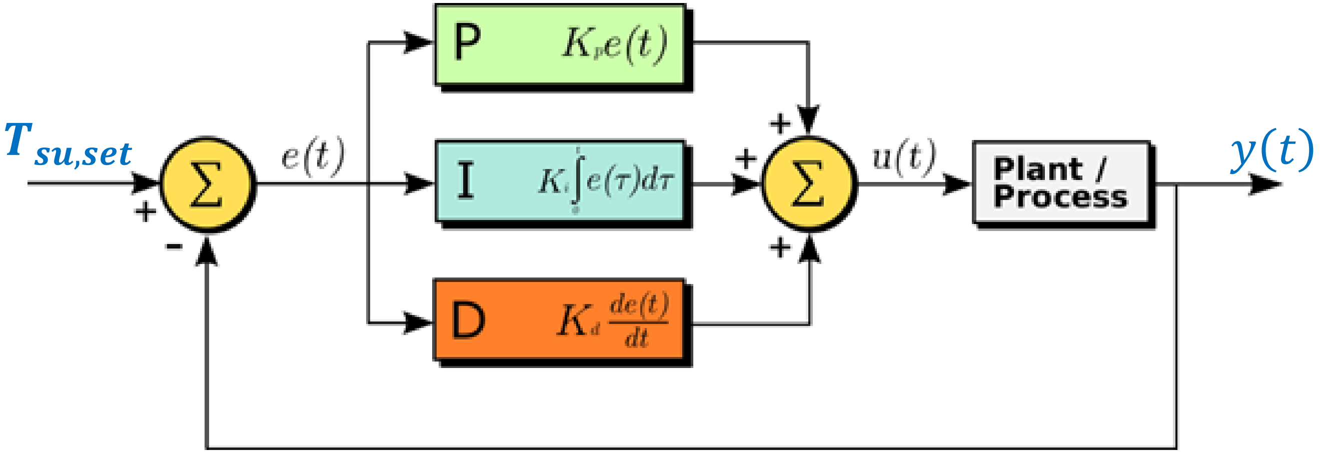
# System operation

## User substations



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

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

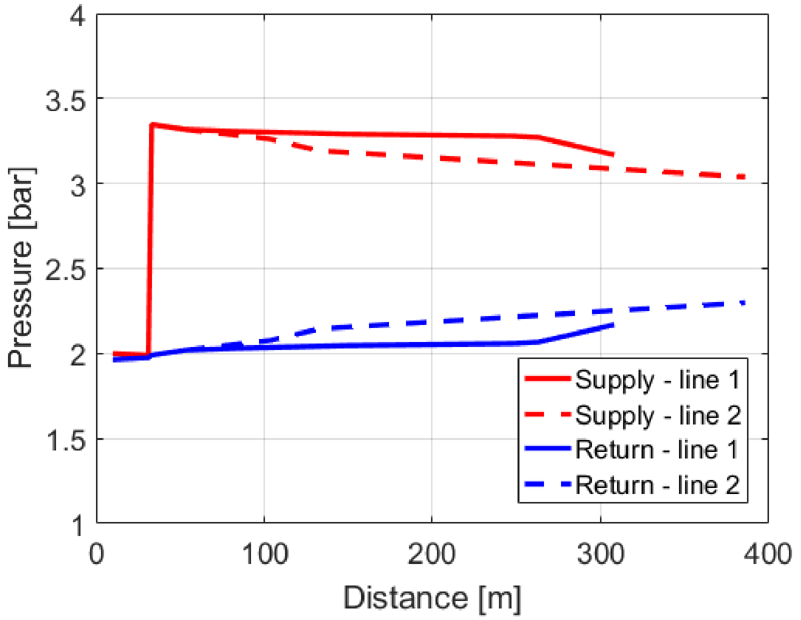


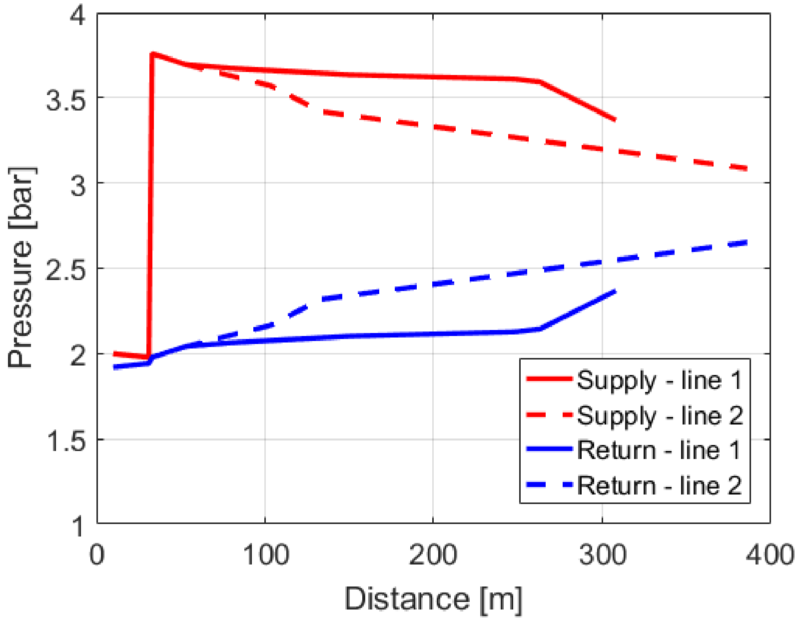
$$y(t) = T_{su,meas}(t)$$

# System operation

**Network**

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

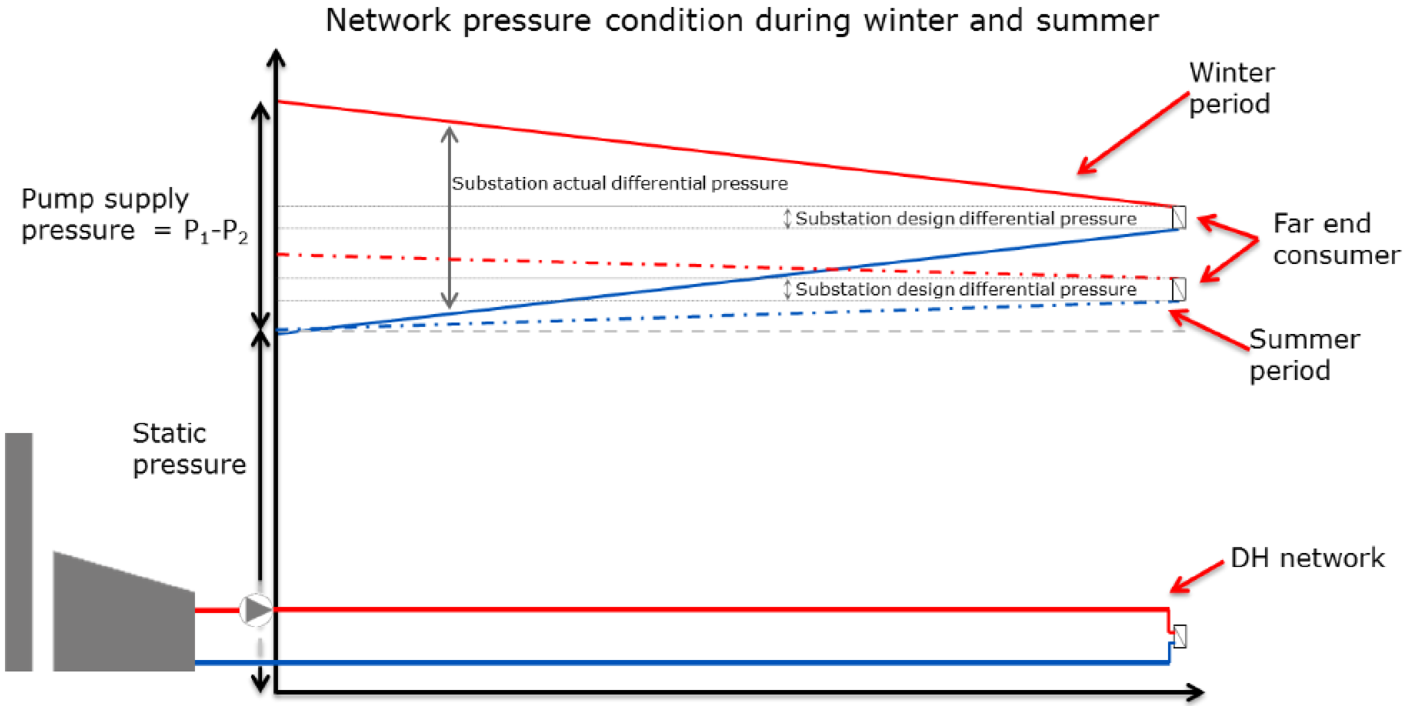




# System operation

## Network

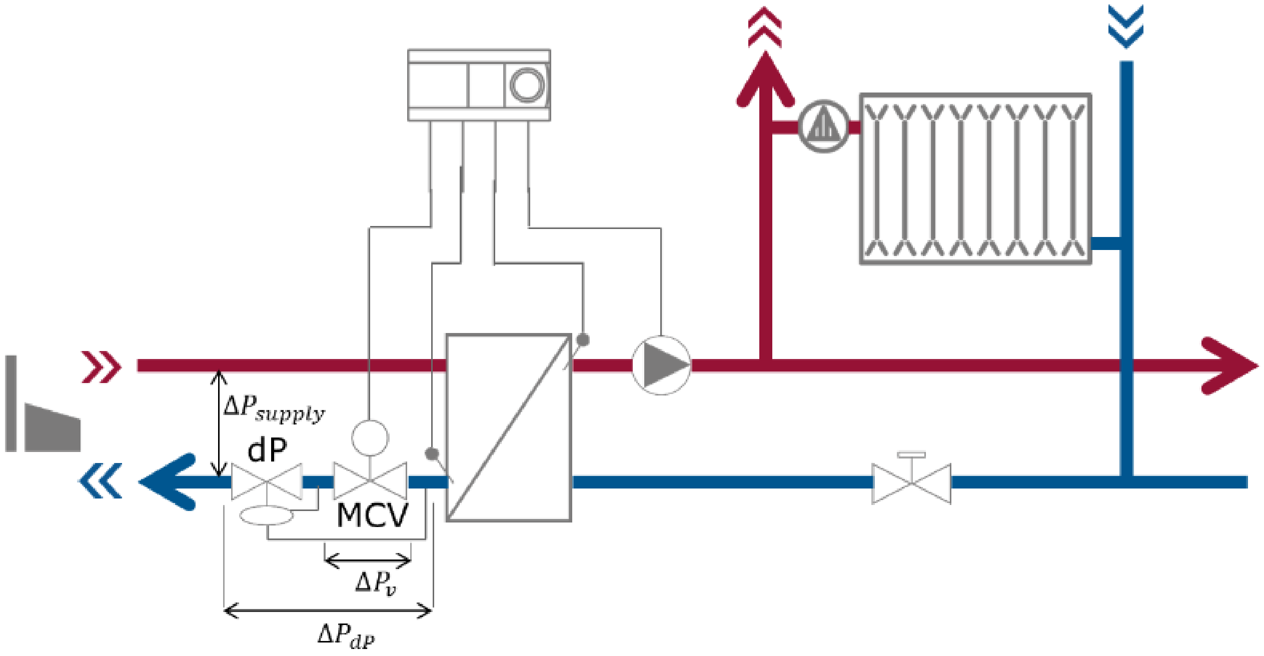
Example of pressure distribution from supply to critical user



# 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).

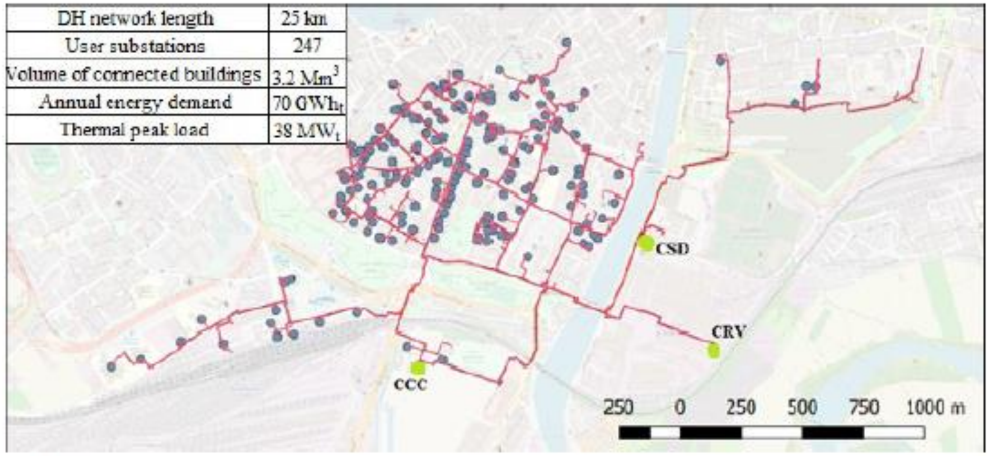
**DH operator**

1) Ensure each customer, especially critical one, has ΔP > ΔPmin (e.g. 150 kPa)
2) Save energy i.e. reduce flow rate (or supply temperature) when heat demand is low

# System operation

## Case study

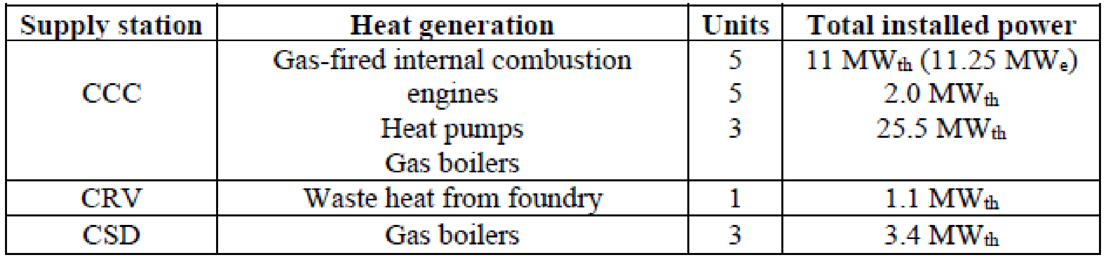
Example from Verona Centro Città's network:



| | |
|---|---|
| DH network length | 25 km |
| User substations | 247 |
| Volume of connected buildings | 3.2 $Mm^3$ |
| Annual energy demand | 70 $GWh_t$ |
| Thermal peak load | 38 $MW_t$ |

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.



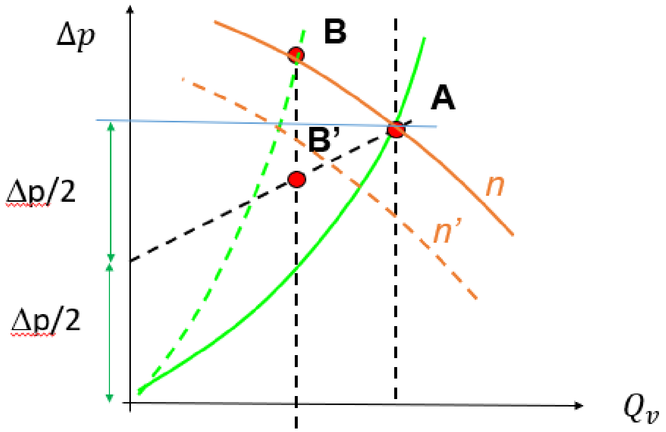
| Supply station | Heat generation | Units | Total installed power |
|---|---|---|---|
| CCC | Gas-fired internal combustion engines<br>Heat pumps<br>Gas boilers | 5<br>5<br>3 | 11 $MW_{th}$ (11.25 $MW_e$)<br>2.0 $MW_{th}$<br>25.5 $MW_{th}$ |
| CRV | Waste heat from foundry | 1 | 1.1 $MW_{th}$ |
| CSD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

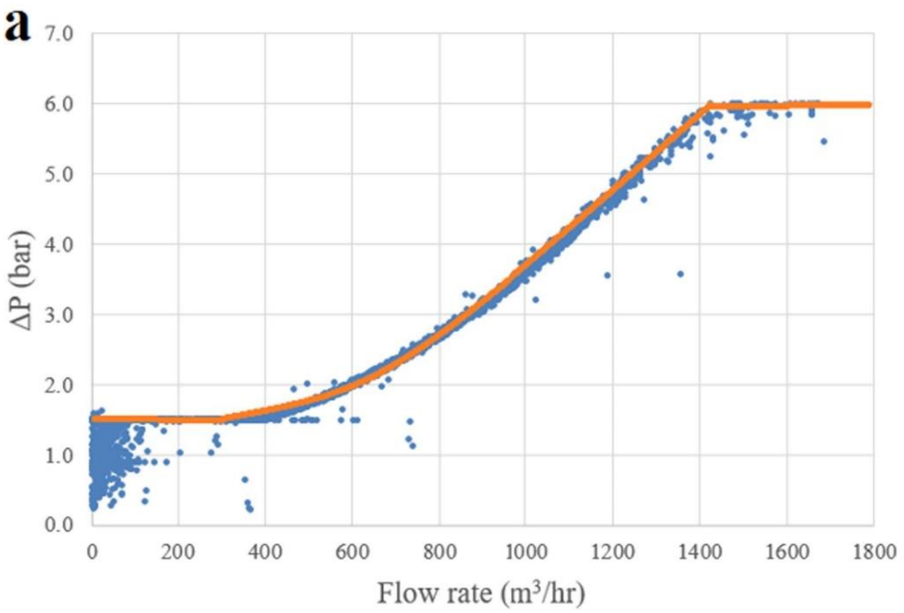
# System operation

## Case study

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

**Control at proportional *Δp***

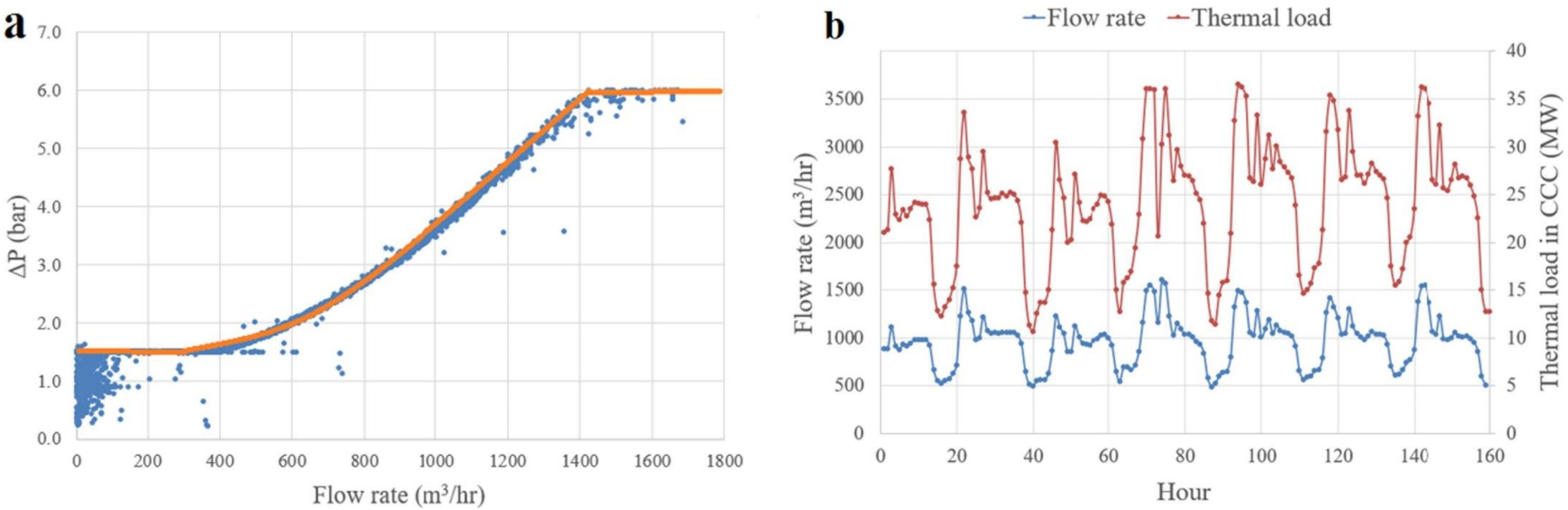




# System operation

**Case study**

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



# System operation

## Heat supply station

Position of additional heat supply stations

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