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Solar Thermal Systems in District Heating Systems

UPV-EHU, Bilbao, 10-12 December 2019

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 768567

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Index (Day 1)

1. Context
2. Performance of ST systems

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Index (Day 2)

3. District Heating Systems
    - Evolution
    - Temperature levels
    - Network structure
    - Design criteria
    - Operation criteria
    - Integration of Renewables & Waste Heat Sources
4. Solar Thermal in DH
    - Large Solar
    - Storage
    - Distributed Solar

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Index (Day 3)

5. Solar Thermal in DH (cont.)
6. Wrap-Up

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3. District Heating Systems

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3.1 Evolution

- Some historic references
  - Roman Baths
  - Chaudes-Aigues (France)
- 1st generation. Steam Based systems (xxx – 1930)
  - Very high temperatures & presurized pipes
  - Non-optimal efficiency, reliability & safety
  - Still in use in Paris and New York
  - For areas with large heat density

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3.1 Evolution

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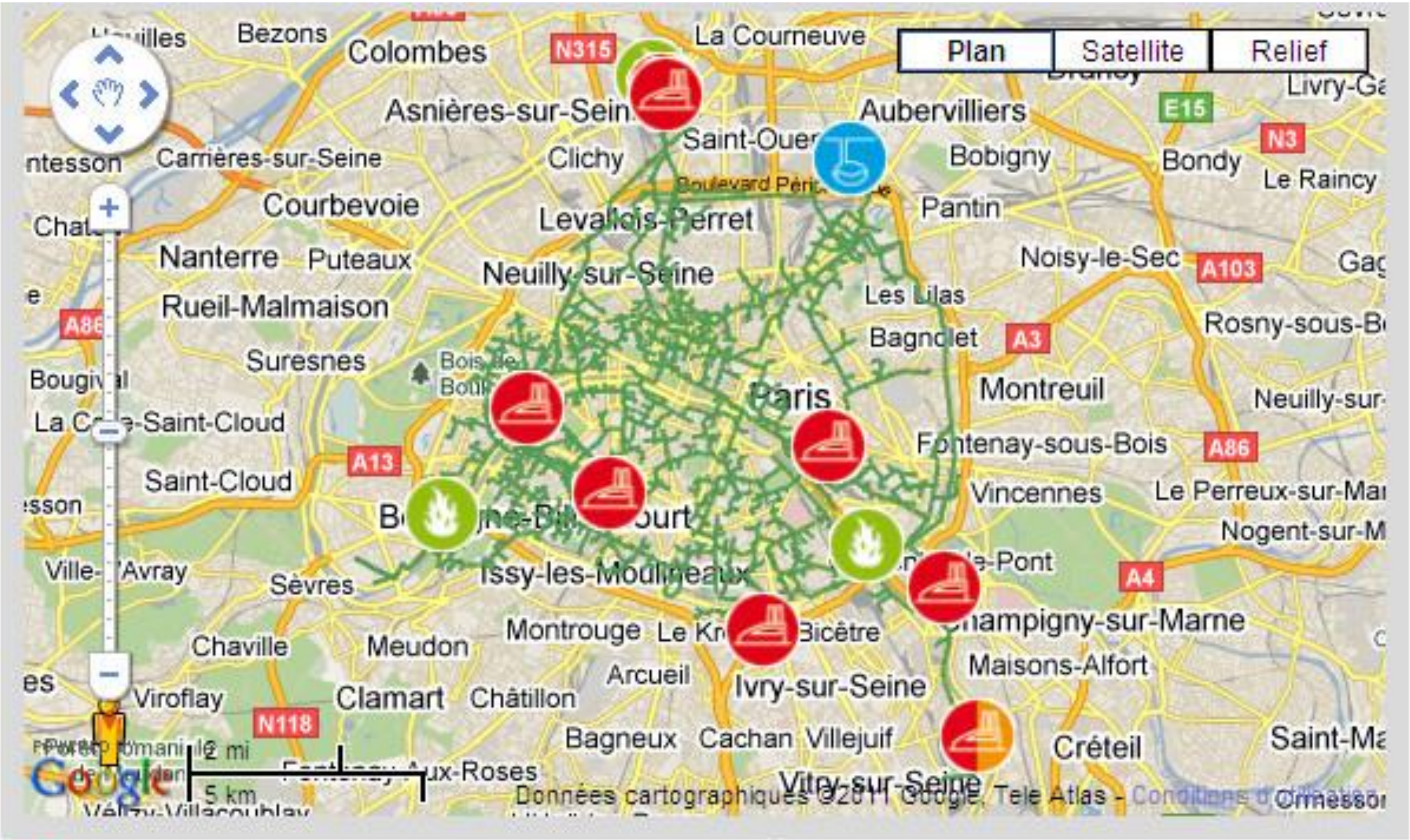

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3.1 Evolution

- 2nd generation. Overheated water (1930 – 1970)
  - > 100 ºC
  - Coal and oil-based systems
- 3rd generation. Hot water (1970- today)
  - > 55-60ºC
  - Increased efficiency/sustainability of heat sources
    - CHP, Biomass, Industrial waste heat, etc.
  - Increased insulation levels

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3.2 Temperature levels

- Stable conditions for mild weather and summer
  - Compatible with DHW production
  - In some cases, service is interrupted in summer
- Increased temperature levels with cold weather
  - Increase capacity with same infrastructure
- Large Flow-Return AT to avoid large pumping costs

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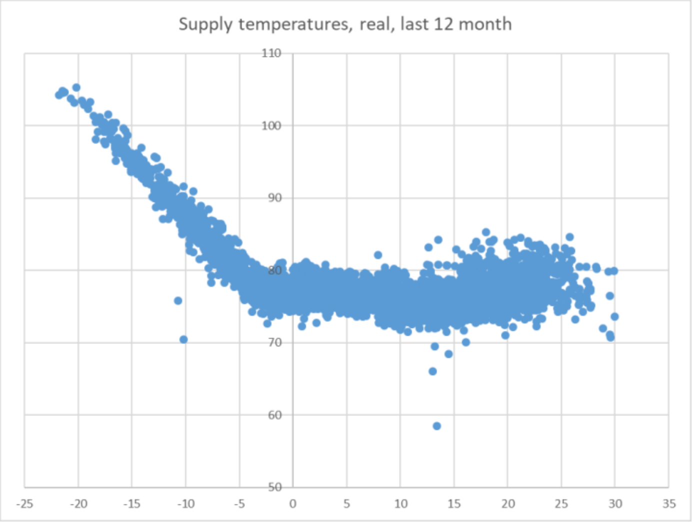
3.2 Temperature levels



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3.3 Heat production structure

- One (or various) low cost producer. As BASE HEAT PRODUCTION TECHNOLOGY
  - CHP (with additional revenue from electricity production)
  - Biomass or waste incineration
  - Industrial waste heat
  - Large boilerplant (e.g. fuel-based)
- Peak producers activated if required
  - Smaller & more expensive technologies
  - Commonly gas-fired boilerplants

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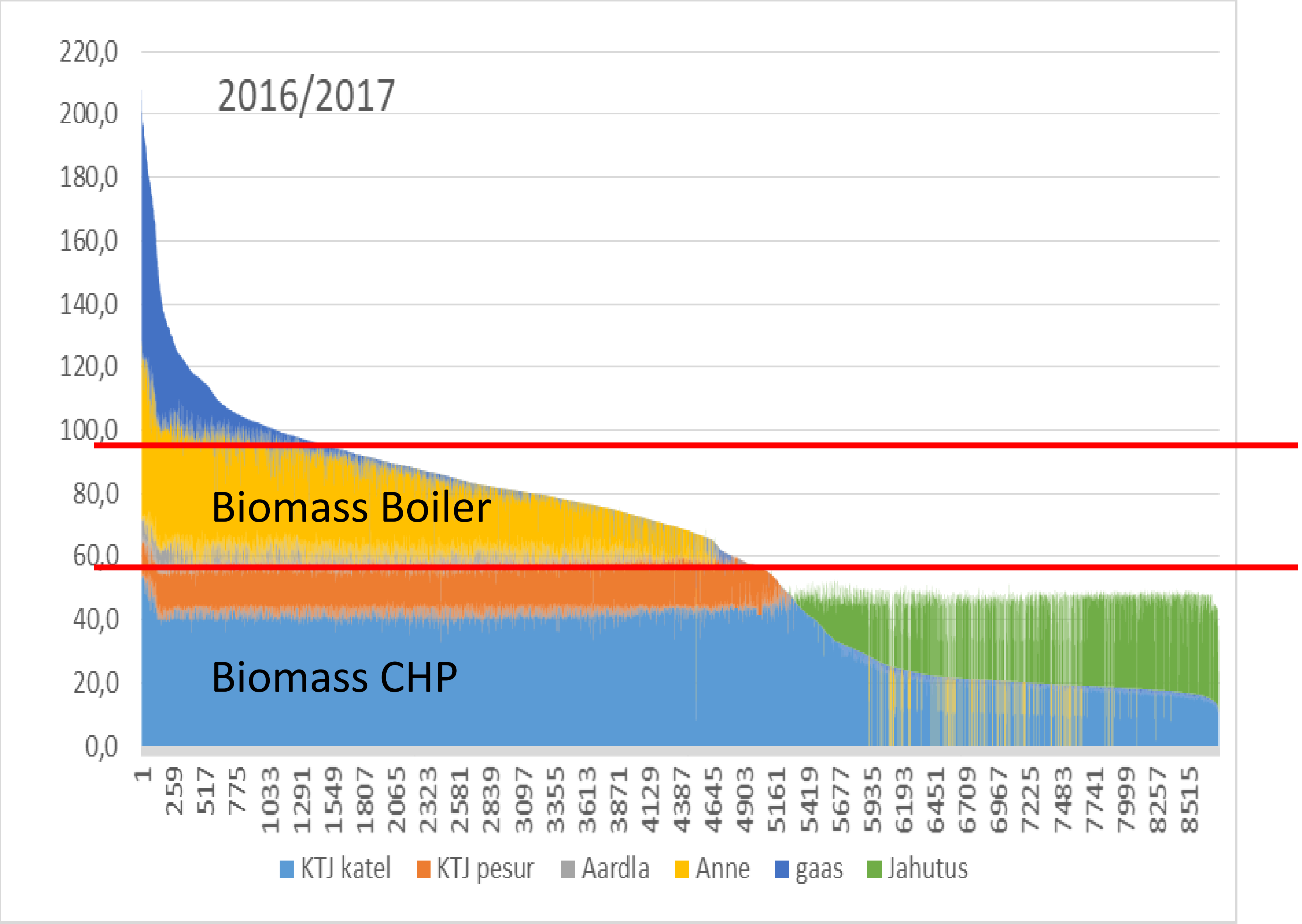

Fortum Tartu. District Heating Network of Tartu, Estonia

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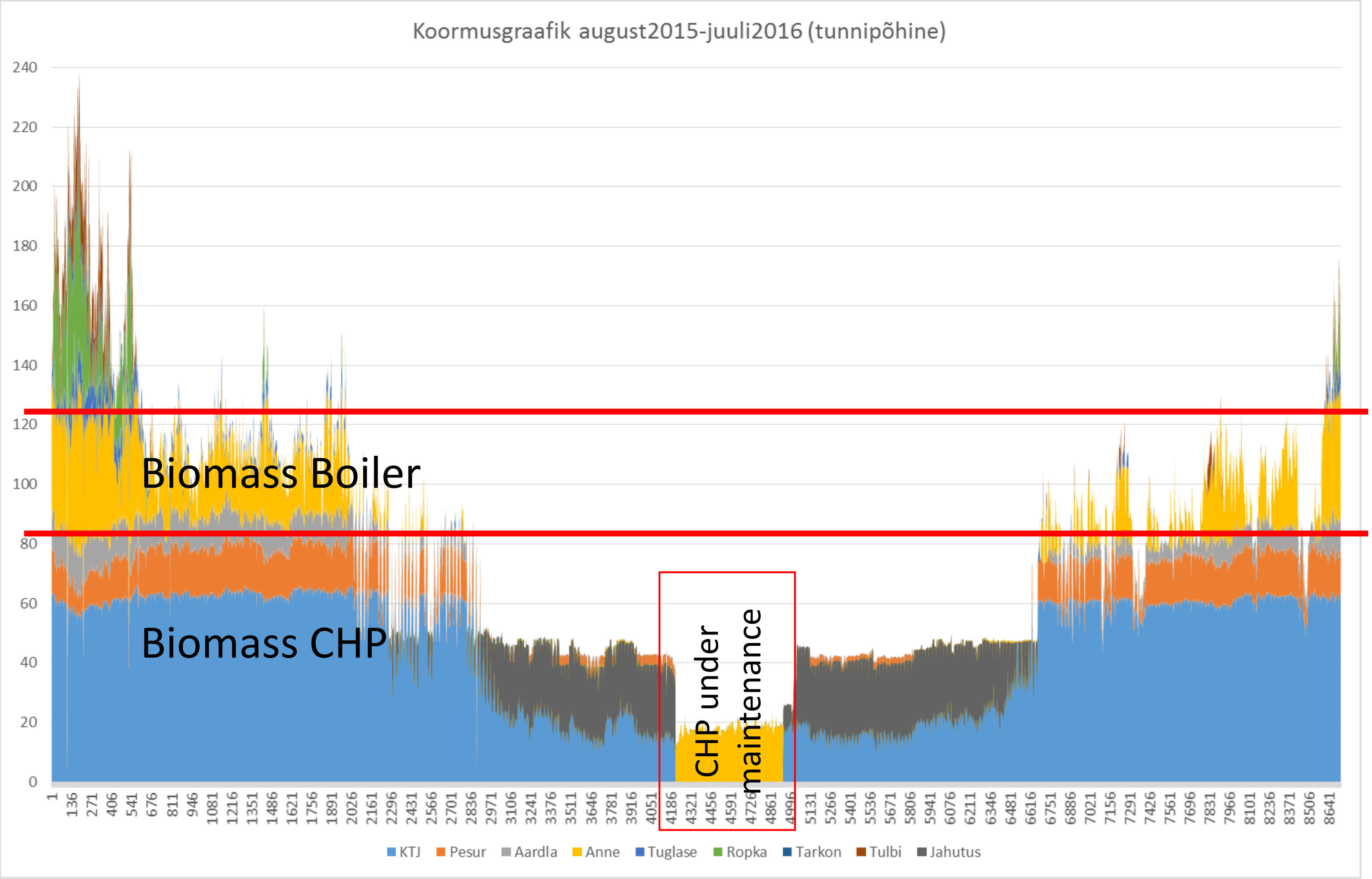

Fortum Tartu. District Heating Network of Tartu, Estonia

3.4 Network Structure

- Small networks:
  - One heat production facility
  - Individual branches
- Large networks:
  - One (large) heat production facility
  - Individual branches
  - Peak boilers installed in branches
  - In some cases, partially meshed system
- Very large networks
  - Transmission lines & Meshed networks

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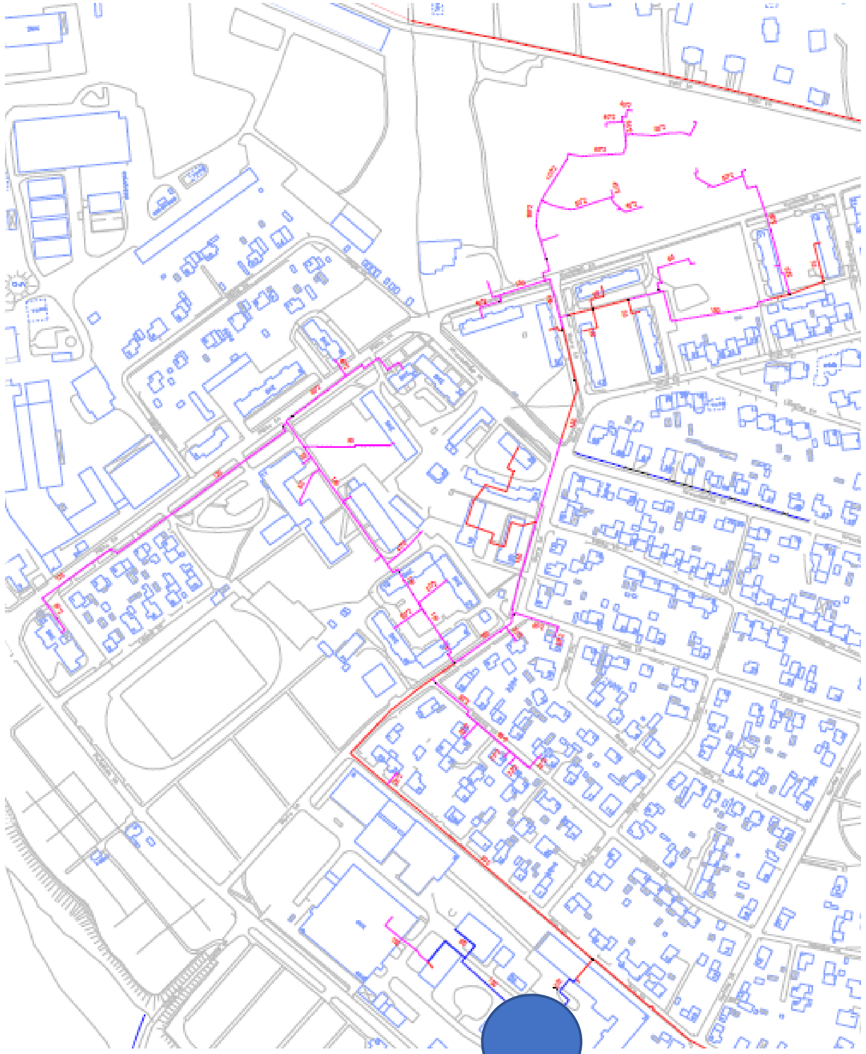
3.4 Network Structure



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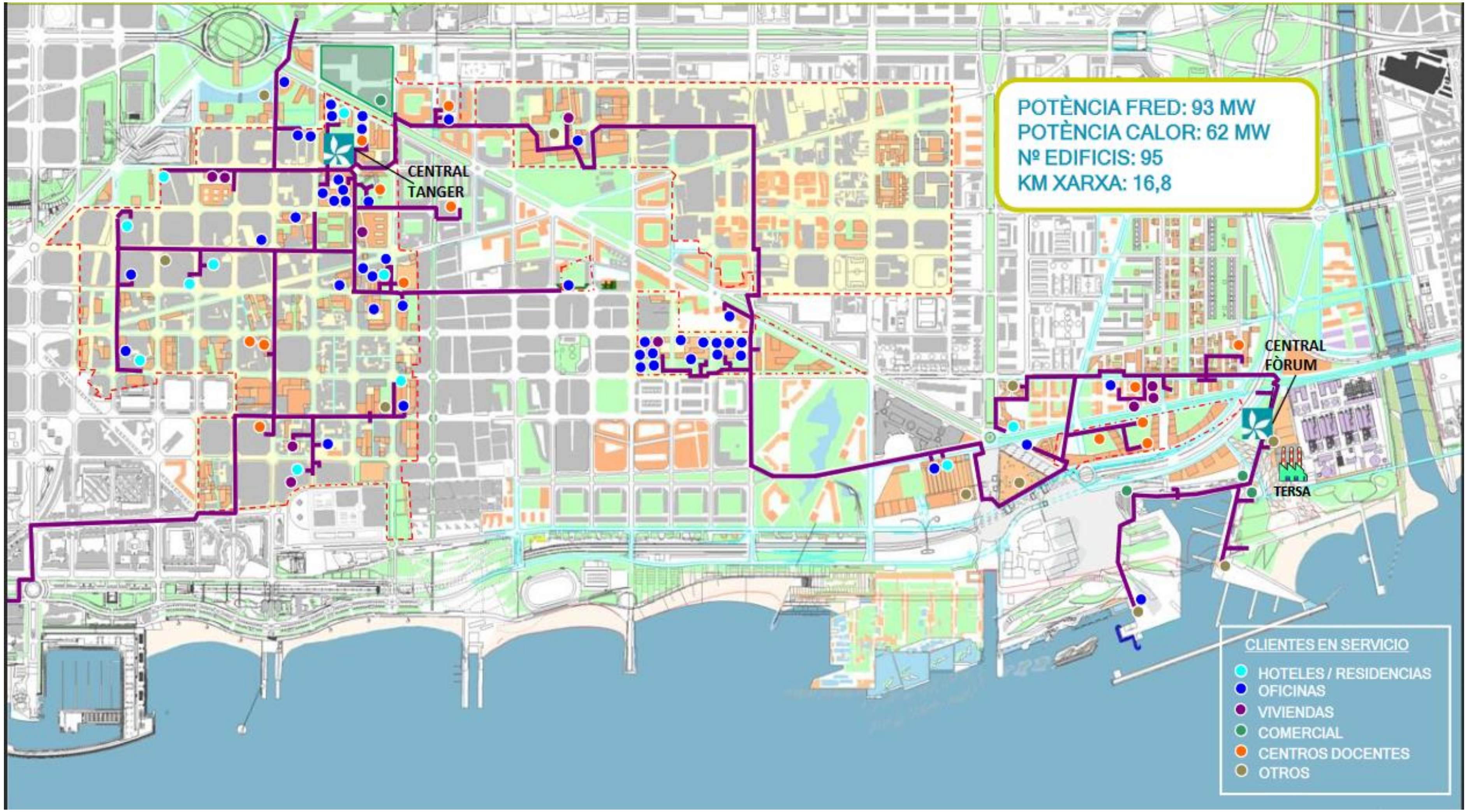
3.4 Network Structure



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http://www.districlima.com/districlima/uploads/descargas/presentaciones%20y%20otros%20documentos/2019_06%20Presentaci%C3%B3n%20est%C3%A1ndar%20Districlima%20(CAST).pdf

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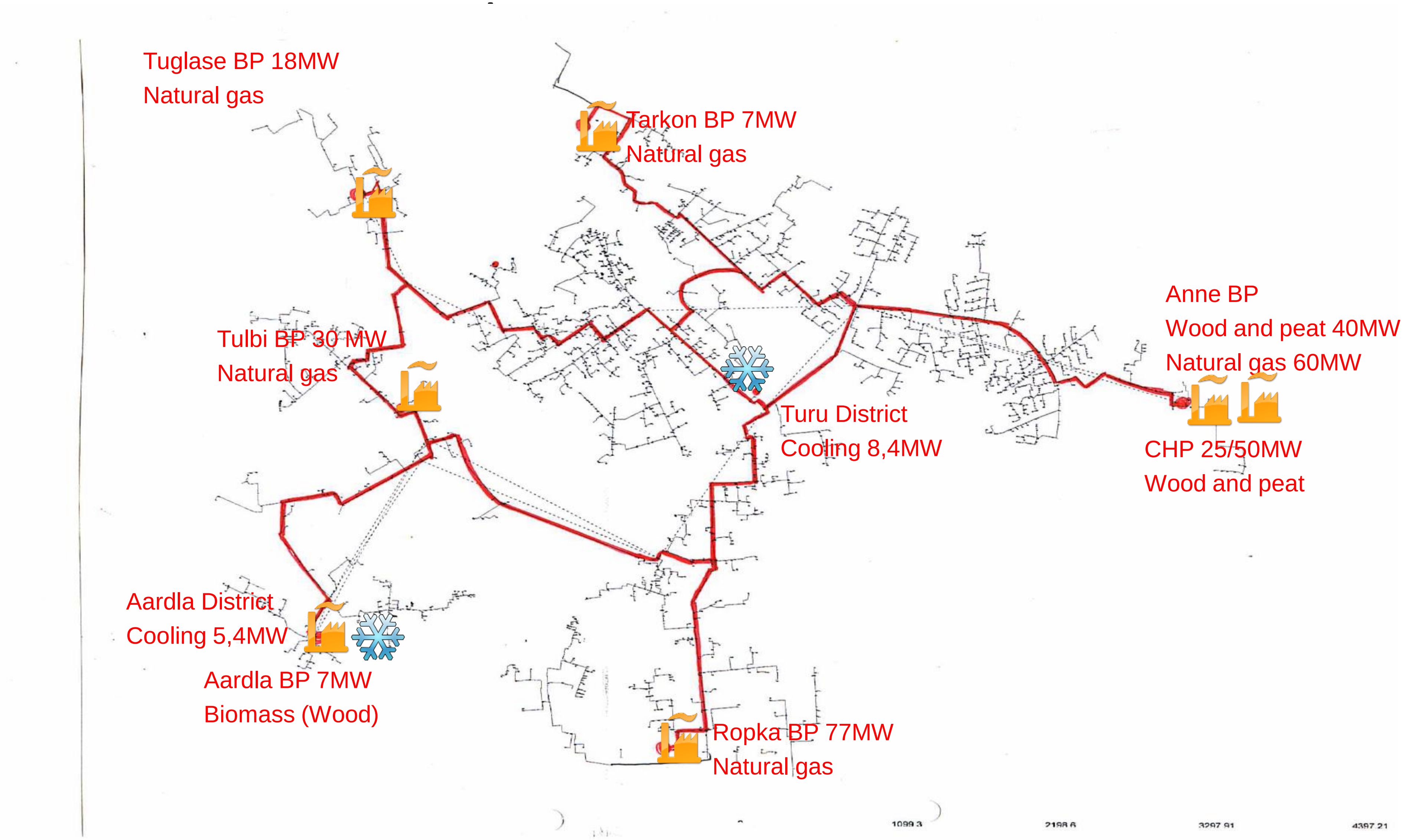

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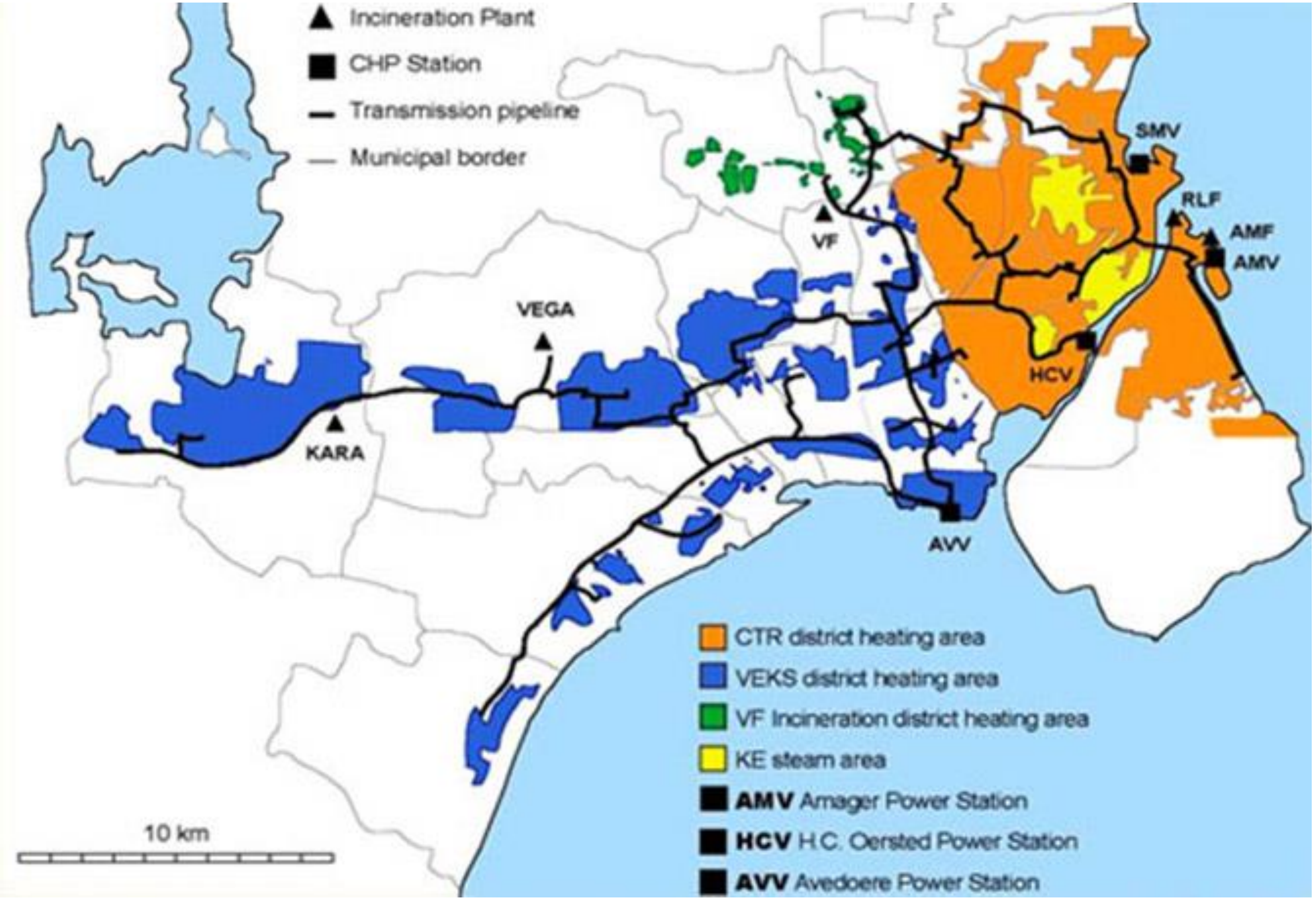
3.4 Network Structure



https://dbdh.dk/dhc-in-denmark/characteristics/

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3.5 Design criteria (consumer-side)

- Deliver maximum heat at low (primary-side) Flow
- DHW sizing: temperature independent
- Space Heating sizing:
  - For typical winter conditions (at low Temperature)
  - For cold winter conditions (at high Temperature)
- Space Cooling sizing:
  - At stable DC temperature. DC already quite cold. Need to avoid frosting.
- Serviceability issues

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3.5 Design criteria (consumer-side)

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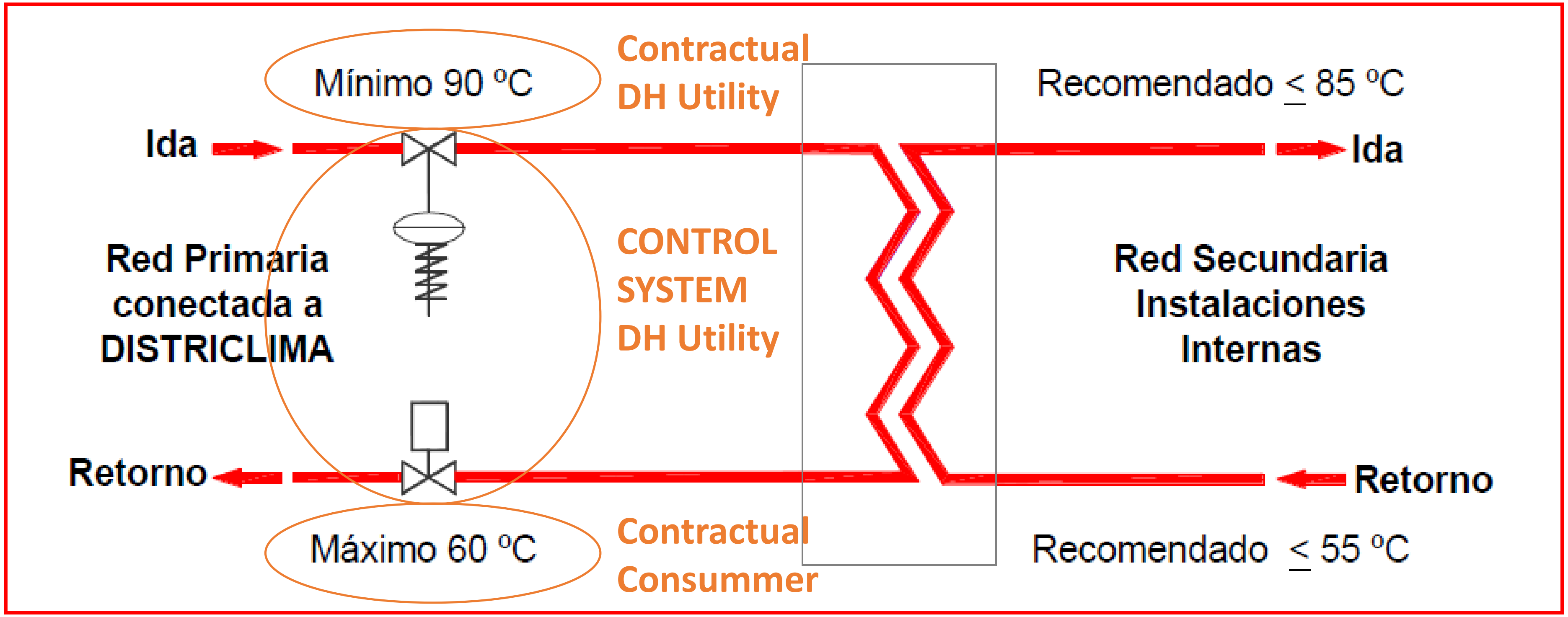

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3.5 Design criteria (consumer-side)

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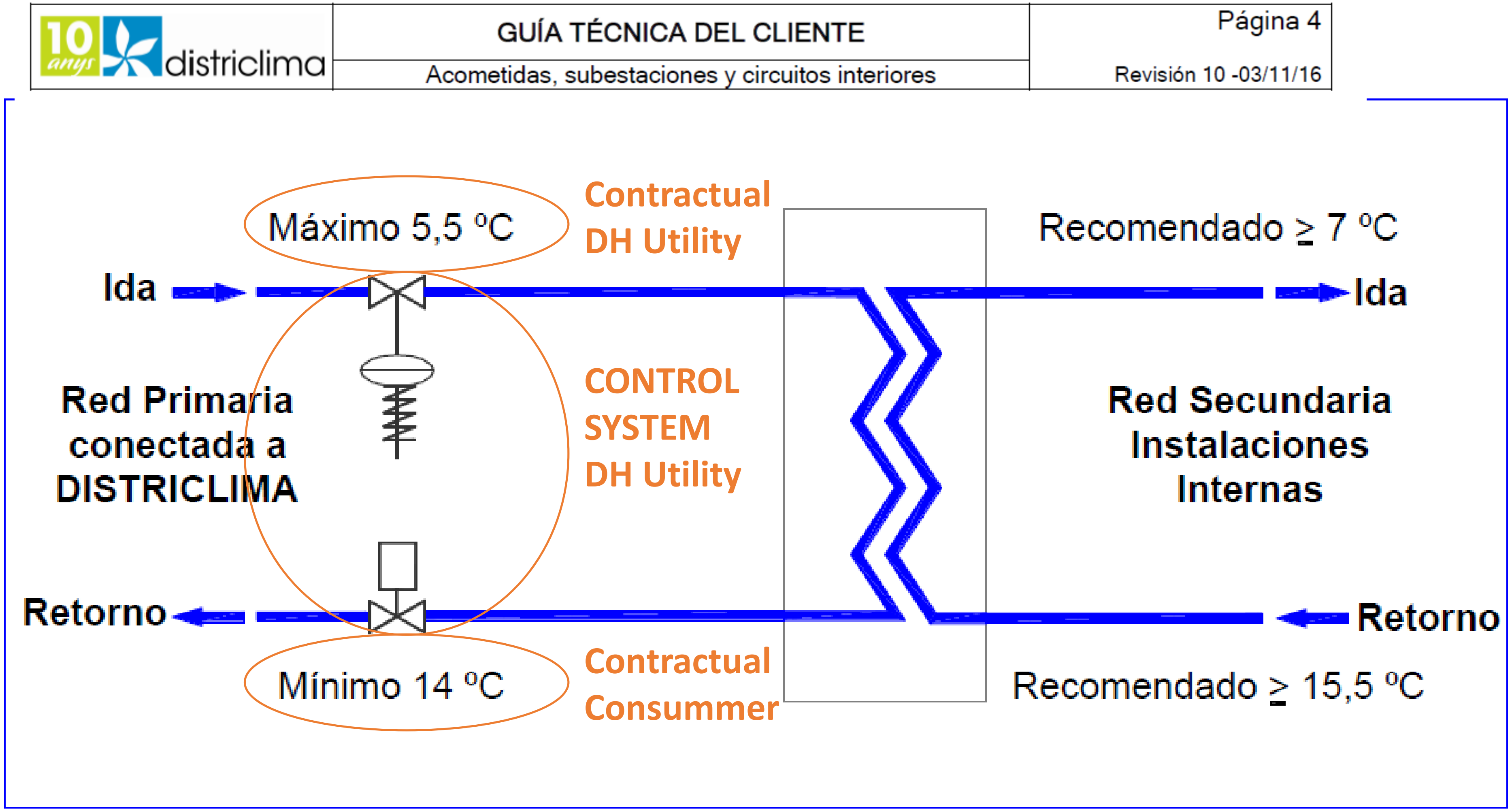

3.5 Design criteria (consumer-side)

- Materials & layouts standardized for the full network
- Meters standardized.
  - Data to be provided varies with capacity
    - Small buildings. Total Heat. Even manual reading
    - Large buildings/factories. Automated Reading.
      - Instantaneous power
      - Total heat
      - Instantaneous Flow
      - Total volumen
      - Inlet T
      - Outlet T
      - Secondary-side values

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3.5 Design criteria (consumer-side)

- Materials & layouts -> standardized for the full network
  - Thermal insulation
  - Operational Pressure & Temperature
  - Homogeneous devices across network
- Meters -> standardized.
  - Data to be provided varies with capacity
    - Small buildings. Total Heat. Even manual reading
    - Large buildings/factories. Automated Reading.
      - Instantaneous power
      - Total heat
      - Instantaneous Flow
      - Total volumen
      - Inlet T
      - Outlet T
      - Secondary-side values

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3.5 Design criteria (consumer-side)

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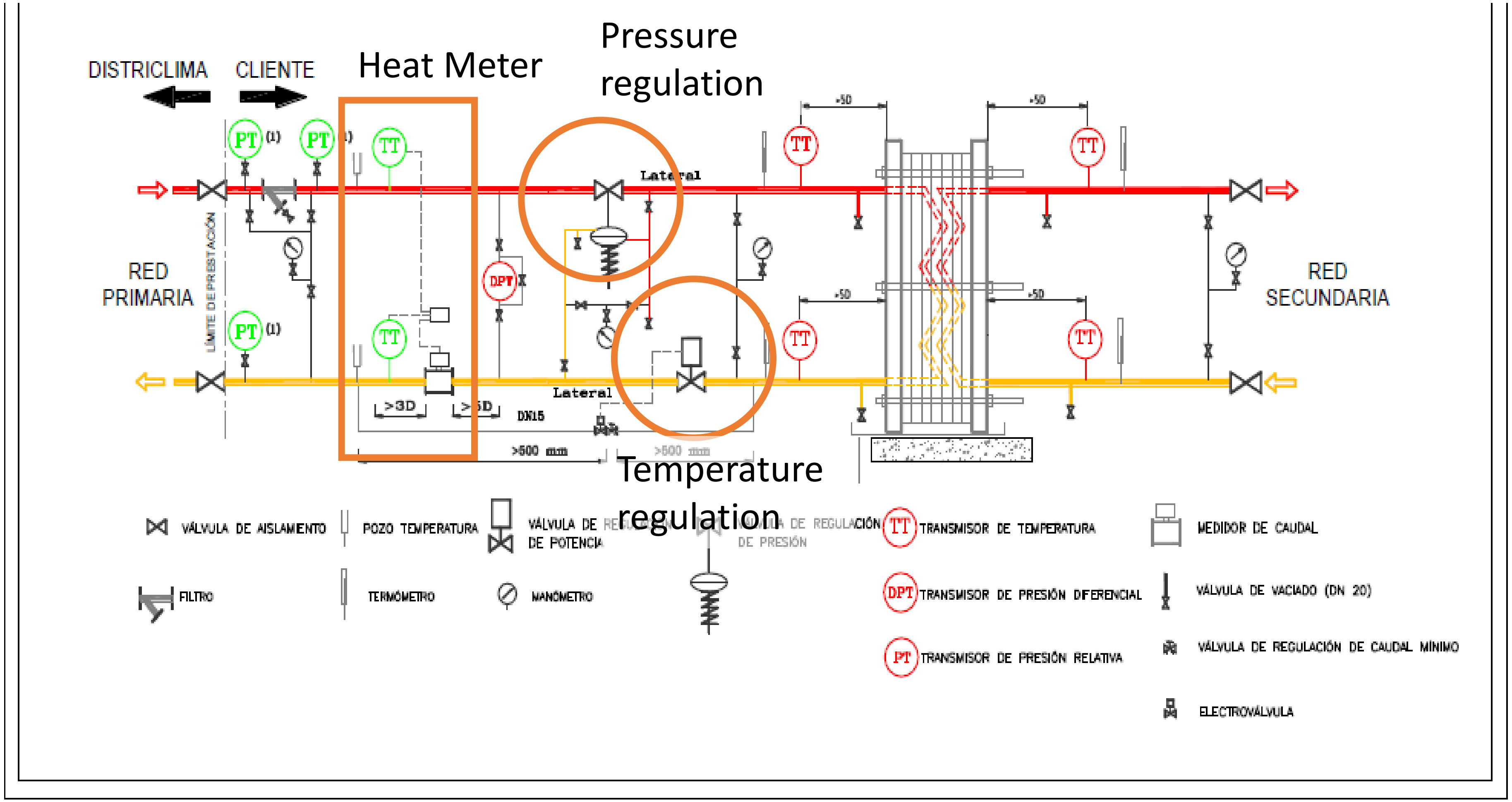

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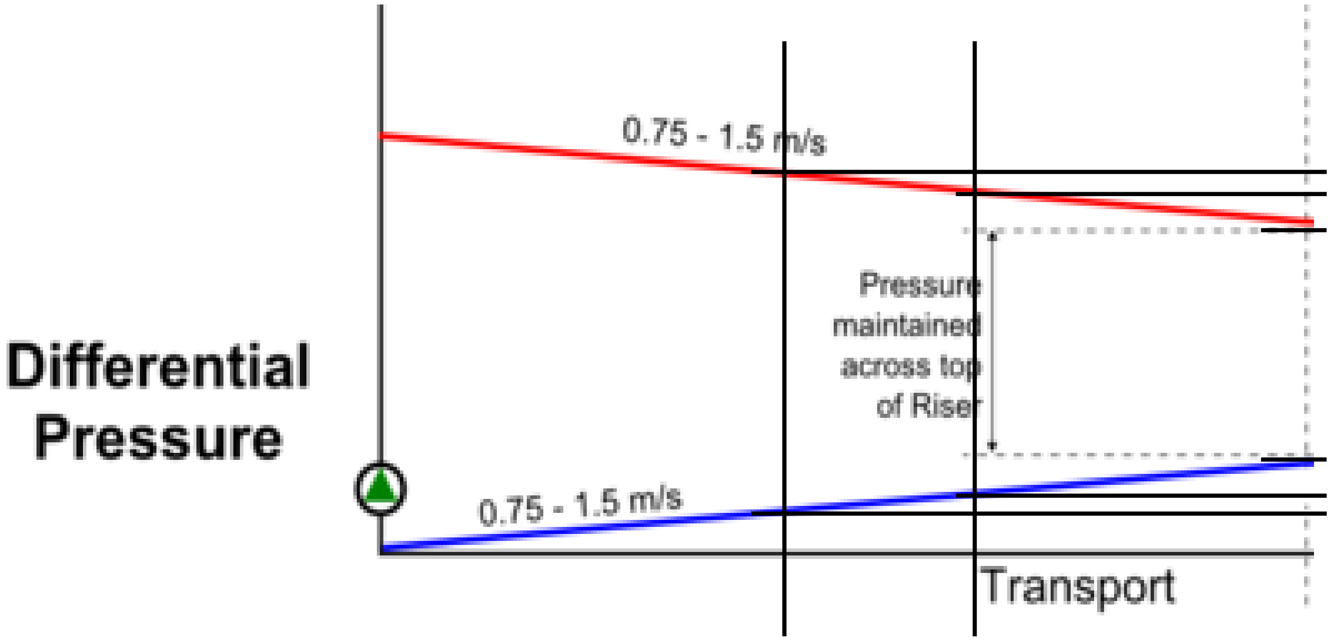
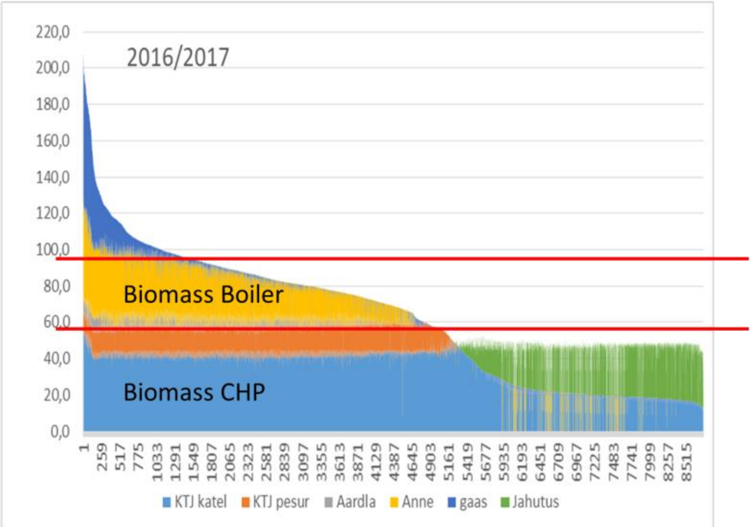
3.6 Presure diagram



- Materials specified for greatest AP
- Presure regulation valve delivers only AP under contract
  - Otherwise Flow/energy to last building in the line would be limited

3.6 Operation criteria

- Guarantee heat supply
  - DHW temperature levels (summer)
  - Weather-dependent temperature levels (Winter)
- Heat production with lowest posible cost
  - Income from electricity production in CHP
  - CO_2 emission taxes



Fortum Tartu. District Heating Network of Tartu, Estonia

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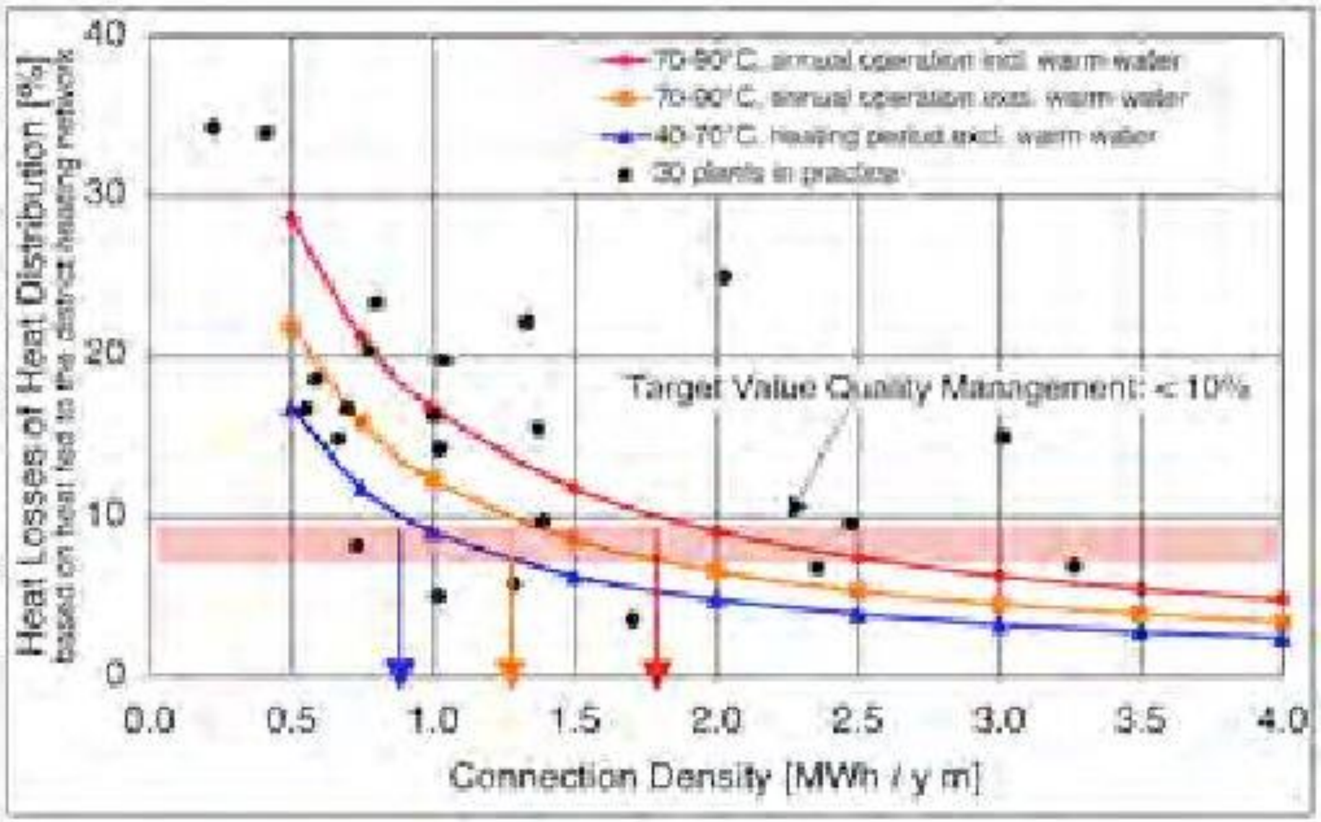
3.6 Operation criteria

- Reduce network loss
  - Lowest posible distribution T



J. Good et Al. Conference on Biomass for Energy, Industry and Climate Protection, Rome 2004

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3.7 Integration of Renewables & Waste Heat Sources

- Industrial waste heat
- Solar thermal Systems
- Low grade heat (heat pumps)
  - Geothermal
  - Lakes/Rivers
  - Exhaust from cooling applications (~20-30ºC)
  - Air-driven heat pumps
- Waste to heat
- CHP systems (?)

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Industrial waste heat

- Process cooling.
  - Commonly reject heat goes to atmosphere.
  - Complex systems which require maintenance & consume electricity
  - Potential (almost) free heat source for DH
- (some examples)

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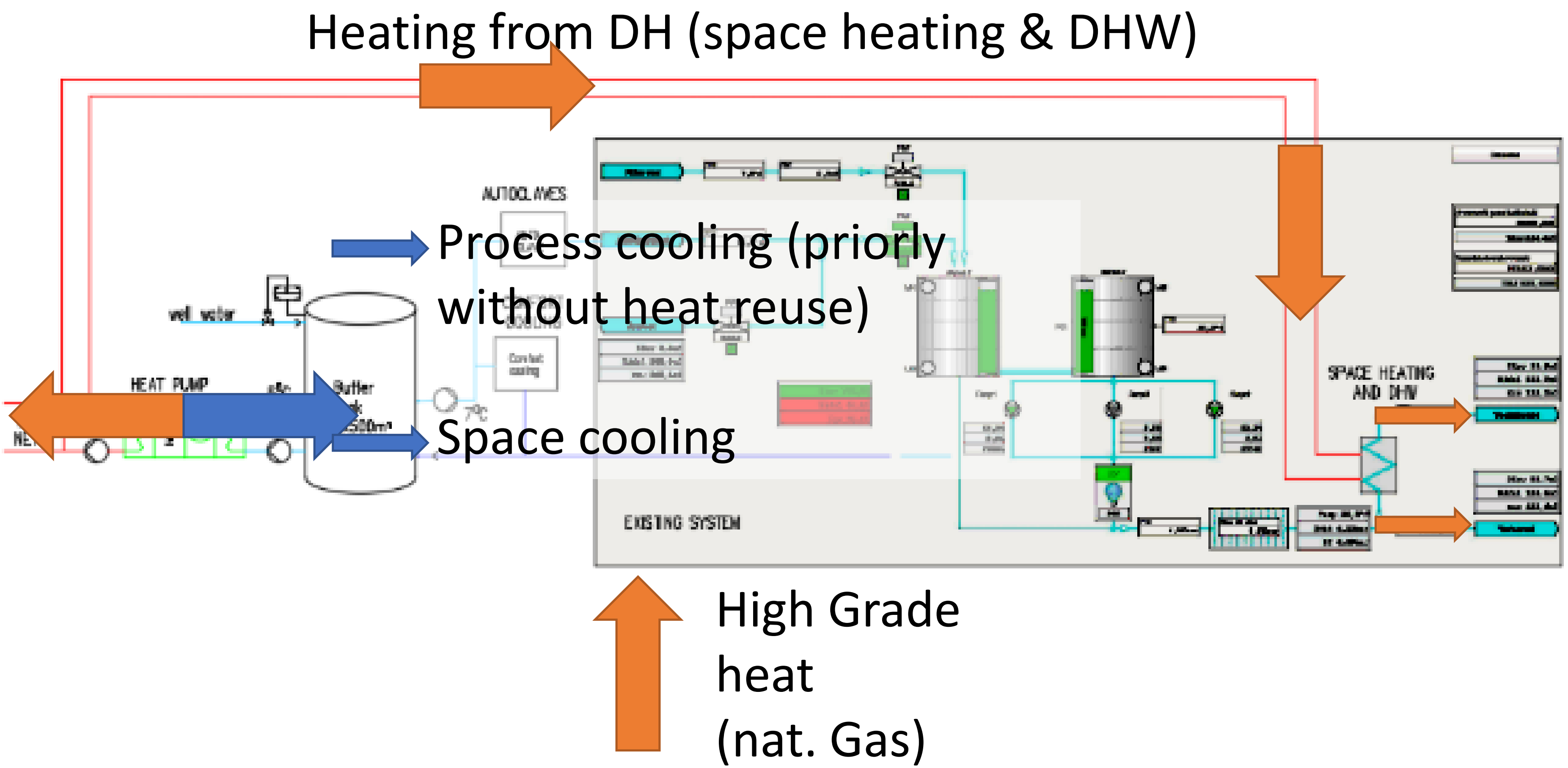
Industrial waste heat



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Industrial waste heat

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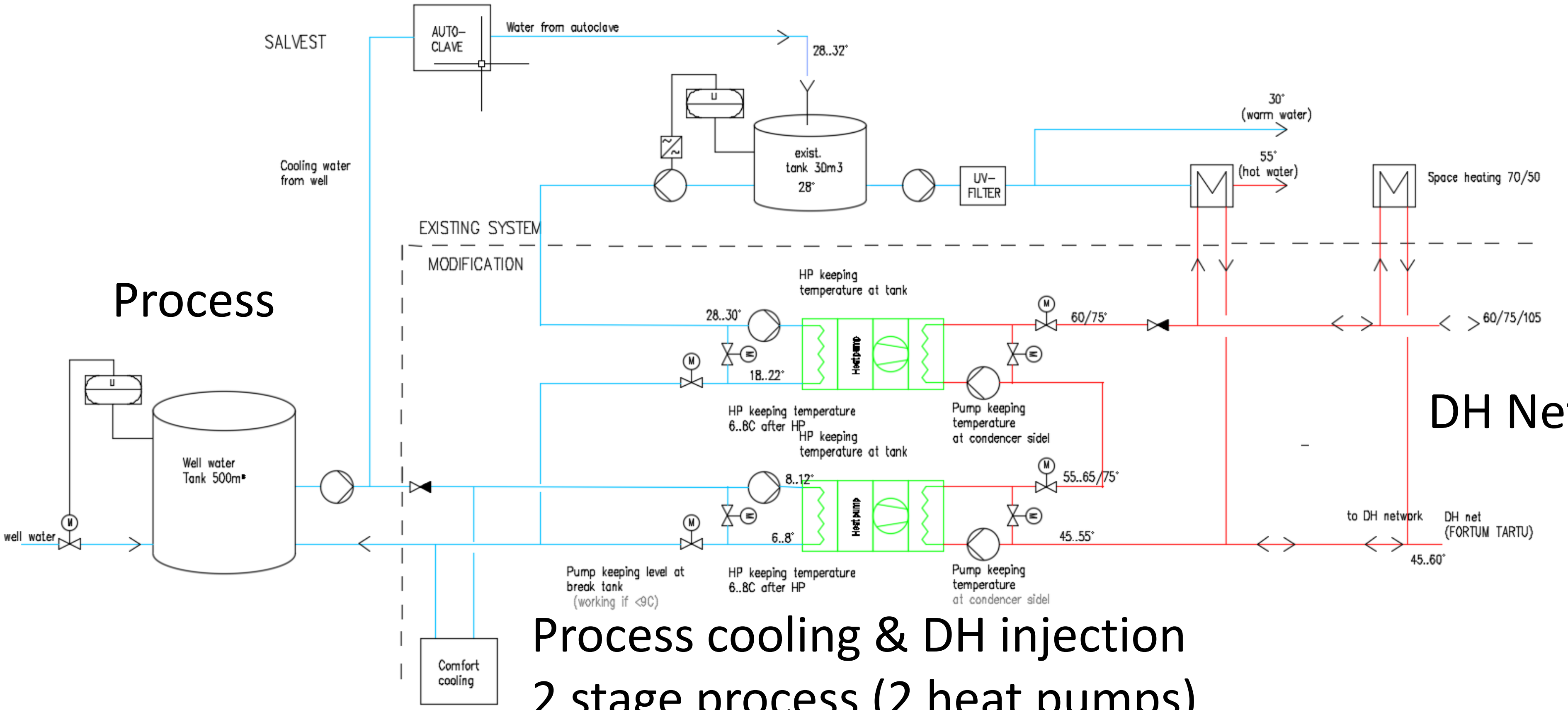
Process



DH Net

Process cooling & DH injection

2 stage process (2 heat pumps)

800 kW

Industrial waste heat

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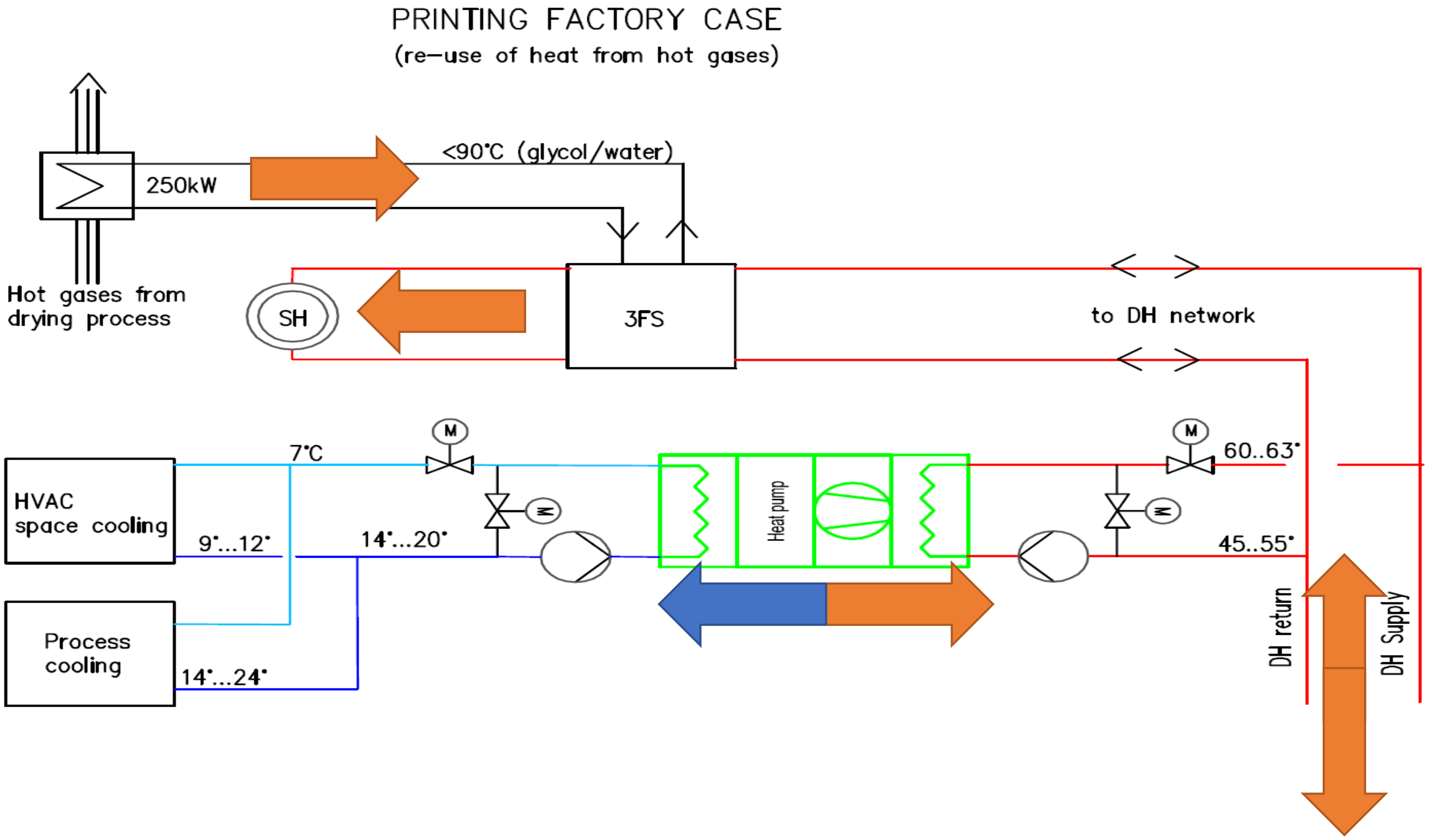

Industrial waste heat

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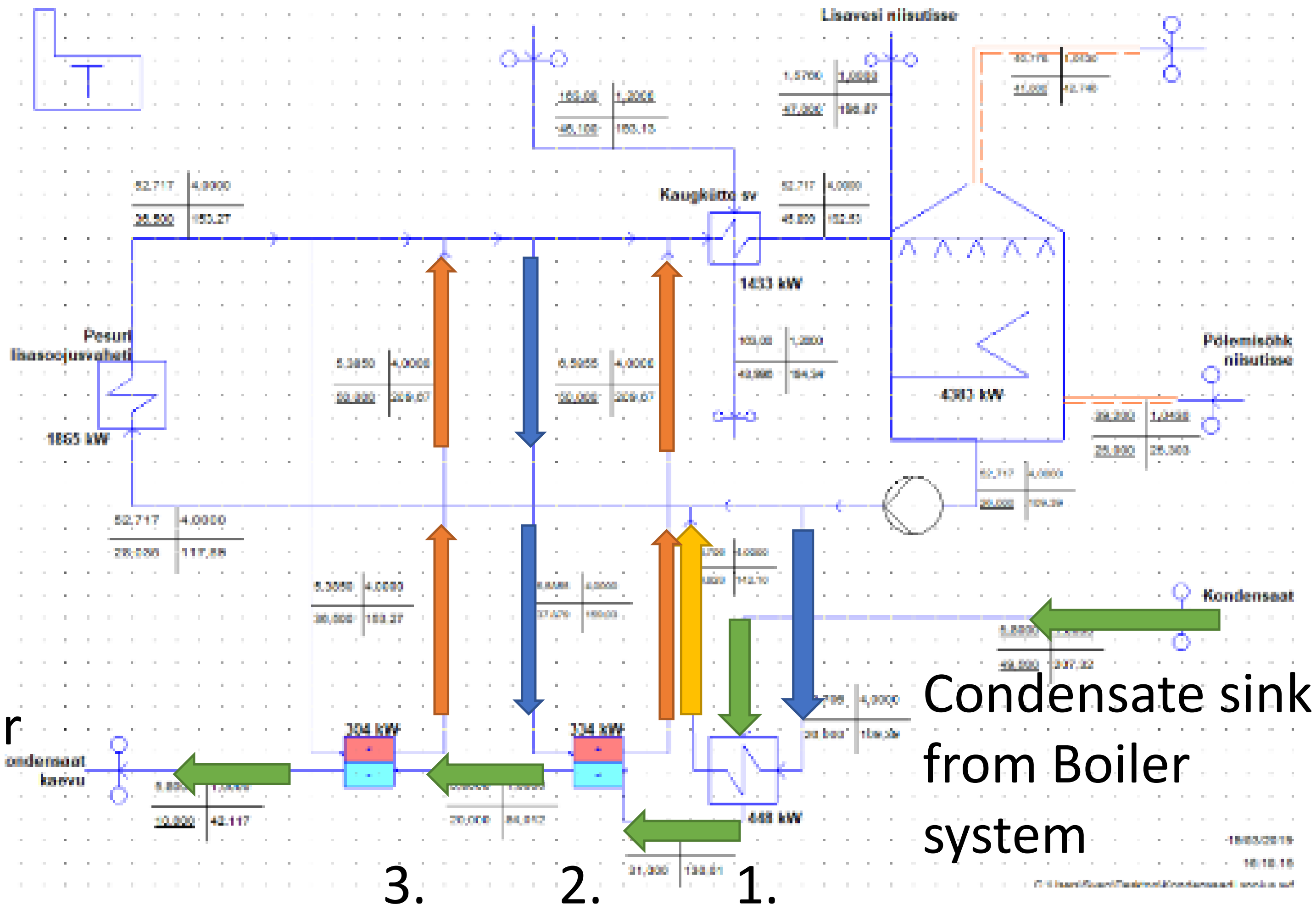
1. Direct heating of economizer water
2. Indirect heating of economizer water
3. Indirect heating of fresh water



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Heat Pumps

- Typical applications.
  - Deep Geothermal
  - Shallow Geothermal
  - Air Driven
- Performance
  - Good COP levels at ~55-65ºC DH Flow
  - Economic performance requires on electricity mix
- Small DH networks
  - Fairly economic
  - Escalable
  - Only requires electric supply (virtually everywhere in EU)
  - Typical heat source in new DH networks

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Heat Pumps

- DH network in Vinge (DK)
  - New town. Presently ca 100 hab.
  - To be populated up to 20.000 hab.
  - 55ºC Flow T.
  - Portable Heat Pump System
    - In container.
    - Composition
      - 2x HP
      - Sotorage tank
      - In-line heater for peak loads
    - Additional containers to be installed in the future
    - To be superseded by larger heat source when town grows
      - Eventually biomass boiler/CHP

Heat Pumps

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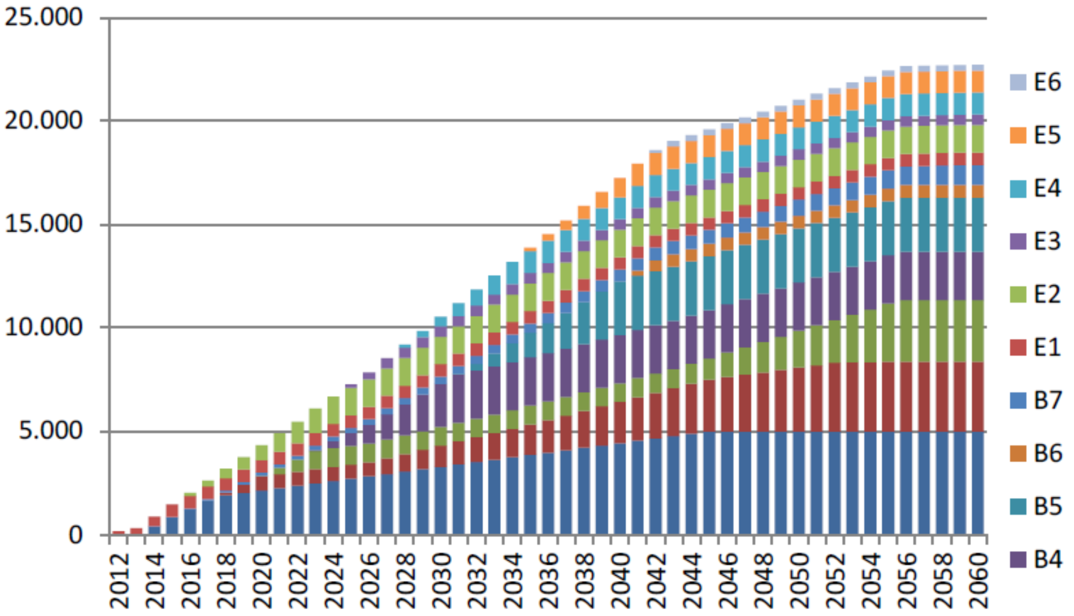
Heat Pumps



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Heat Pumps

- Innovative uses
  - Reject heat from supermarket cooling applications
  - Reject heat from data centres

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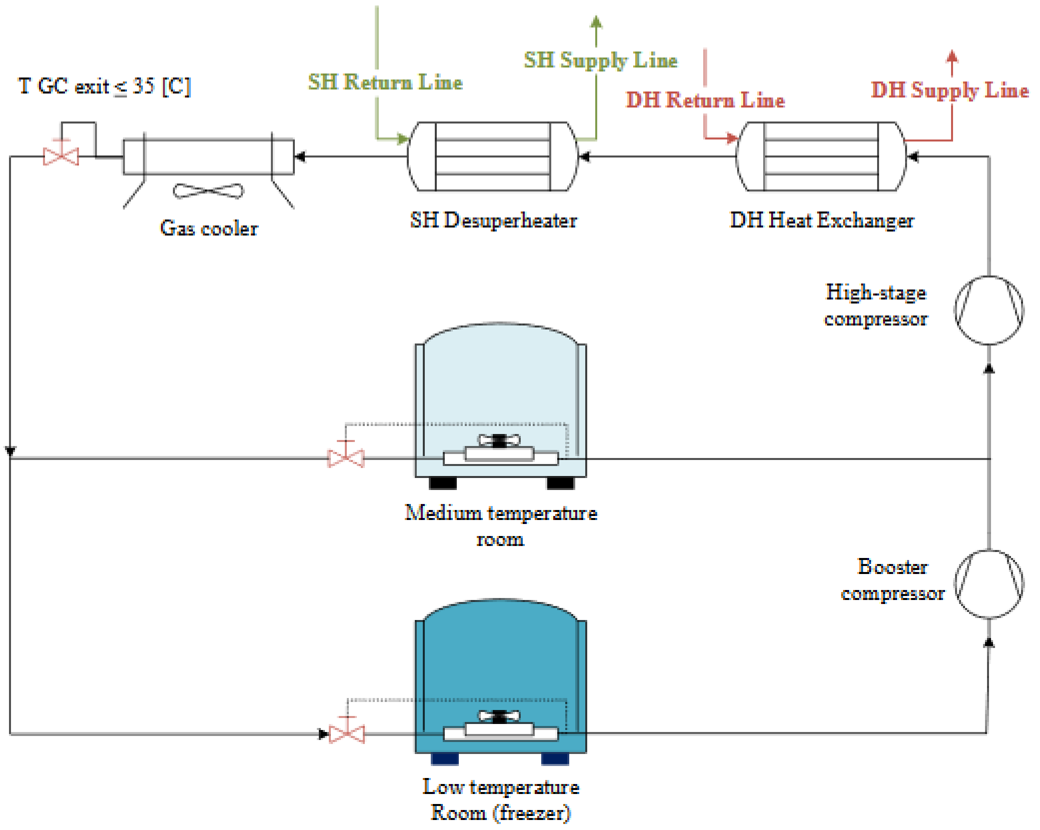
Heat Pumps

- Supermarket



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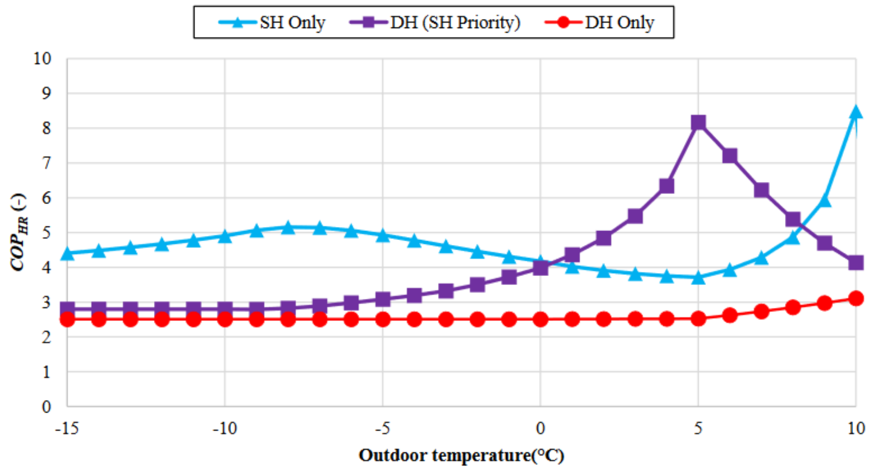

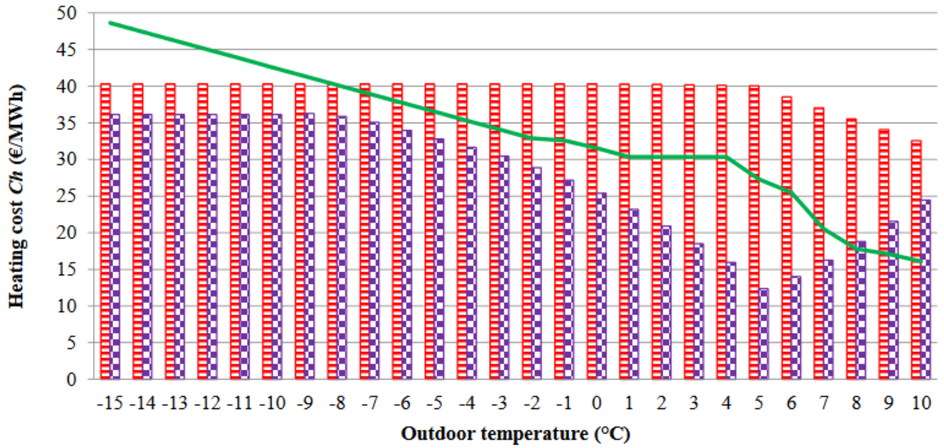

Adrianto, HeatRF Heat Recovery from CO2 Refrigeration System in Supermarkets to District Heating Network, 2018

Heat Pumps

- Reject heat from data centres
- FGH Zurich.
  - Housing Community
    - Various housing blocks, each with specificities (insulation & heating system)
  - Close to 2 main datacentres (Central DCs for Bank & Insurance companies)

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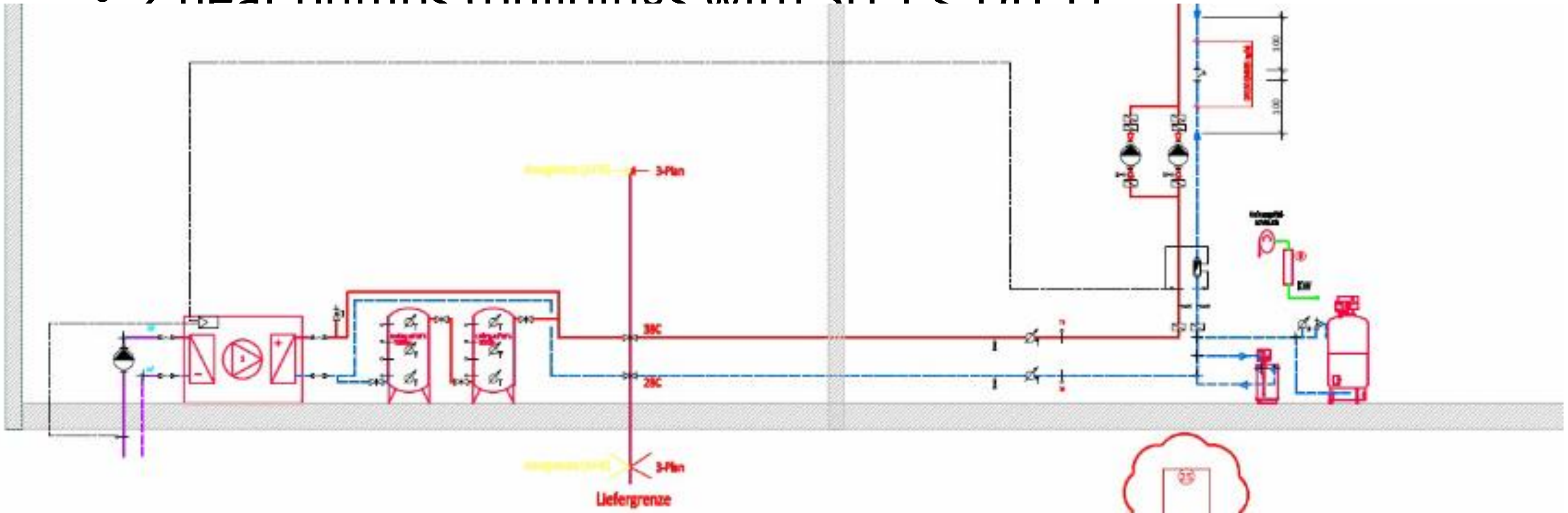
Heat Pumps

- FGH Zurich.
  - “Cold” DH network @ 20-30ºC
  - Heat pump in each block
    - Space heating T according to specific Flow T for buildings
    - DHW T according to standards
  - 1 heat pump (buildings with SH T > DH T)
  - 2 heat pumps (buildings with SH T < DH T)



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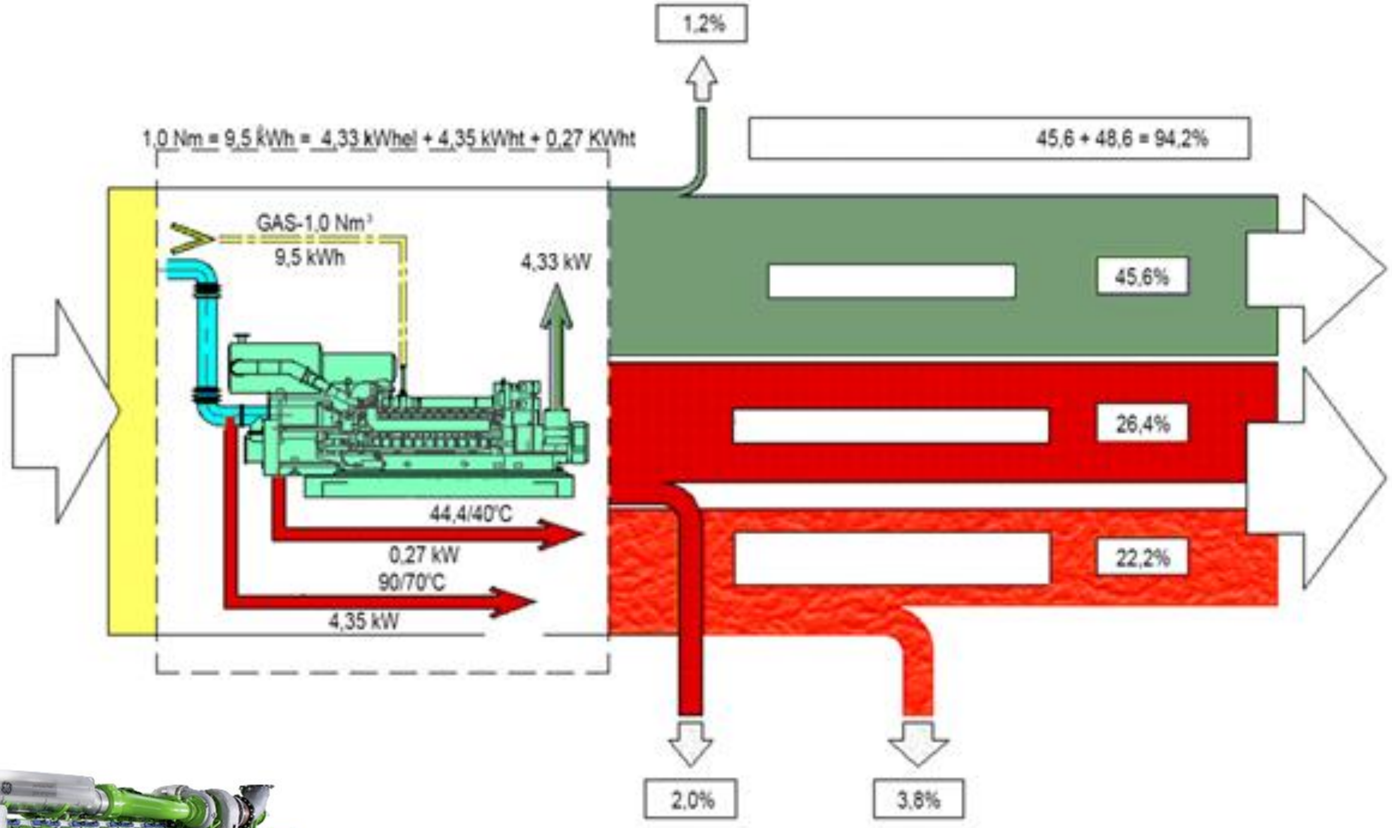
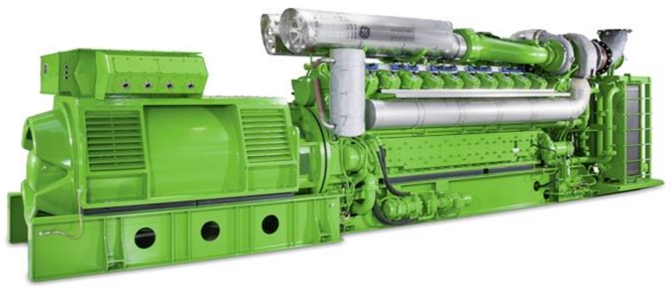
CHP





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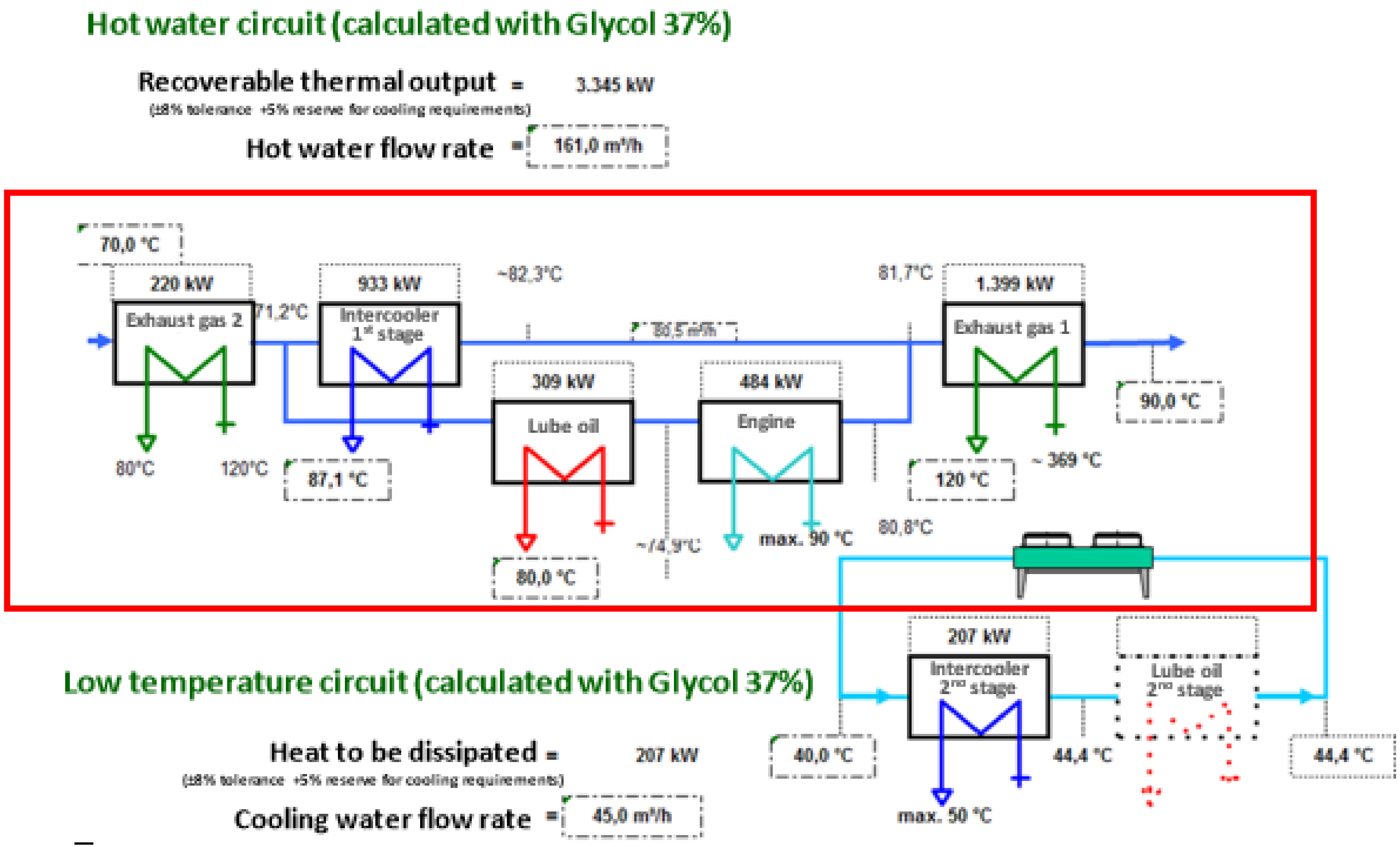
CHP



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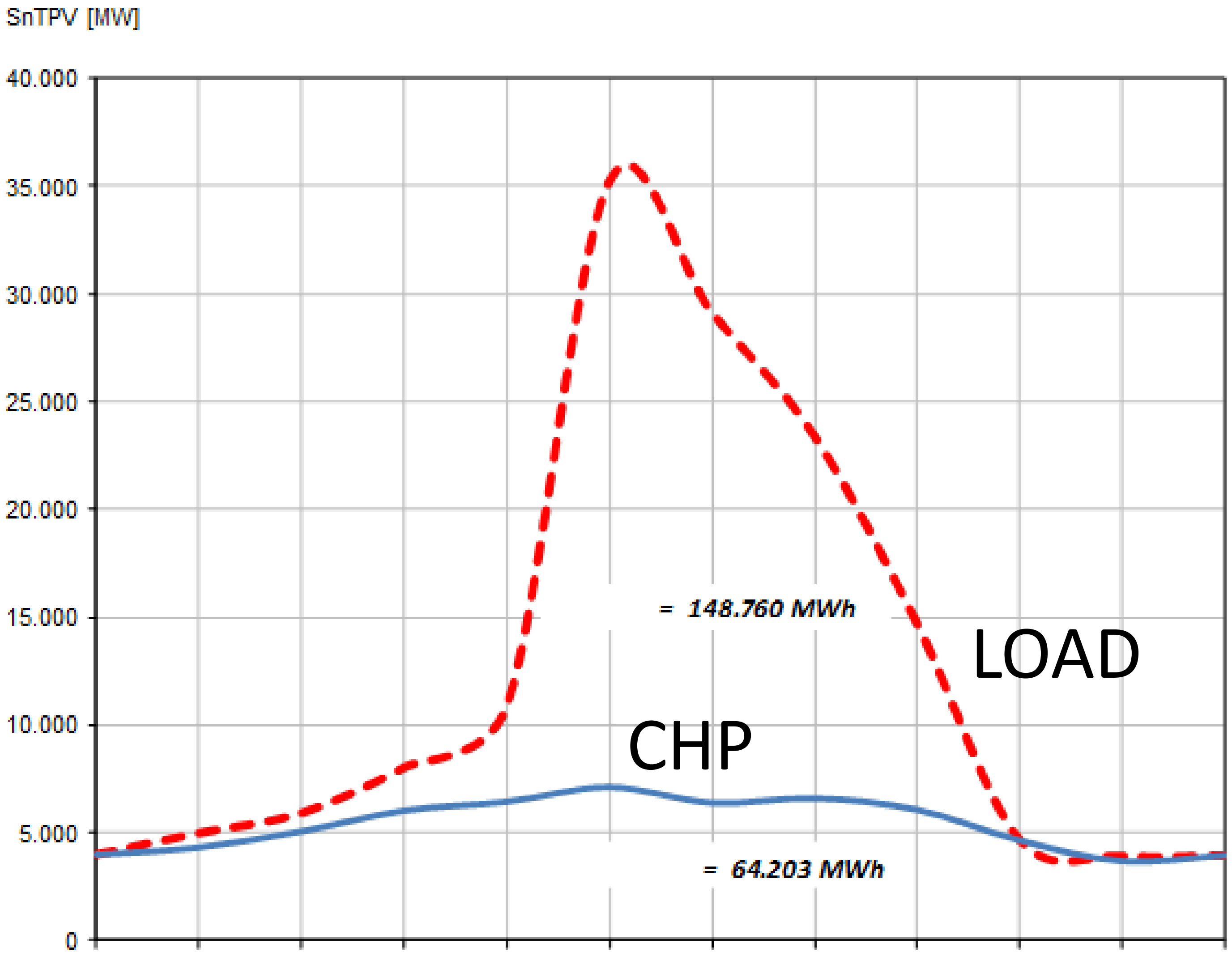
CHP



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CHP

- Nikola Tesla Power plant
  - (Belgrade, 300,000+connetions)
  - Presently Electric power plant
  - Conversion to CHP
  - Connection of condenser to DH netork
  - Within a wholistic plan
    - Reduction of carbon footprint by 45%

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Chinese company to build heating pipeline in Belgrade

Serbia | June 8, 2017 | Comments: 0 | Author: Balkan Green Energy News |

Mali said the EUR 200 million project is very important both because it brings annual savings of about EUR 43 million or about one third of the EUR 140 million which the Belgrade district heating company spends for gas imports.

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4. Solar Thermal in DH

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4.1 Large Solar

- DHs
  - Large & continous heat loads
  - Large energy bills
- ST
  - Discontinous heat production
  - Free heat
  - (isolated systems) non optimal heat usage
  - (isolated systems) expensive to set up & mantain
- Oportunity
  - Optimal heat usage
  - Lower (specific) upfront & maintenance costs
- Drawback
  - Higher temperature levels (than in isolated systems)
  - Transmission losses

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4.1 Large Solar

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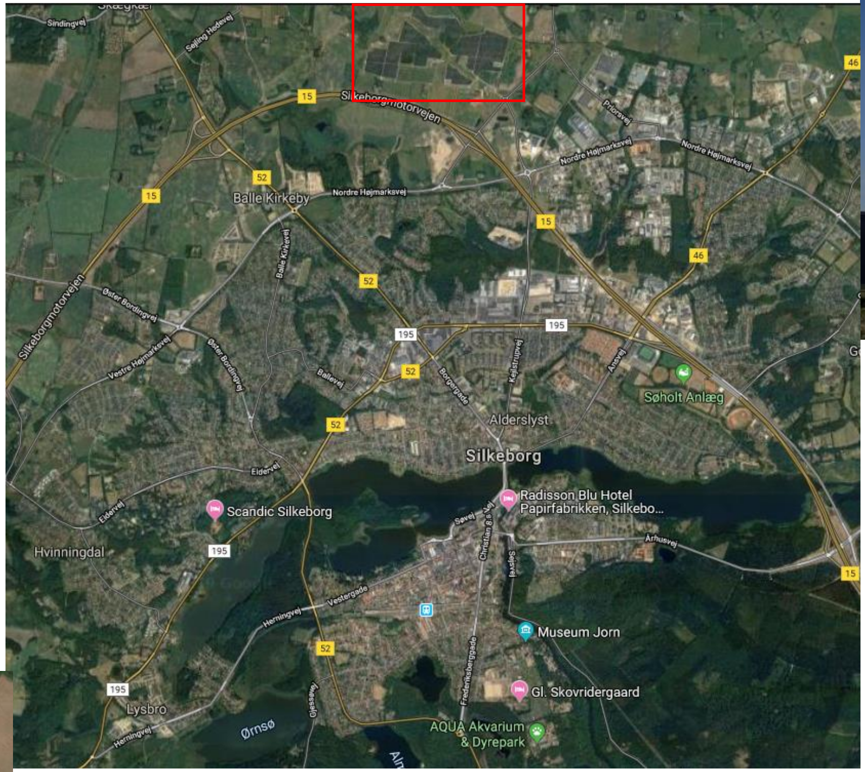

Silkeborg SDH system

http://arcon-sunmark.com

4.1 Large Solar

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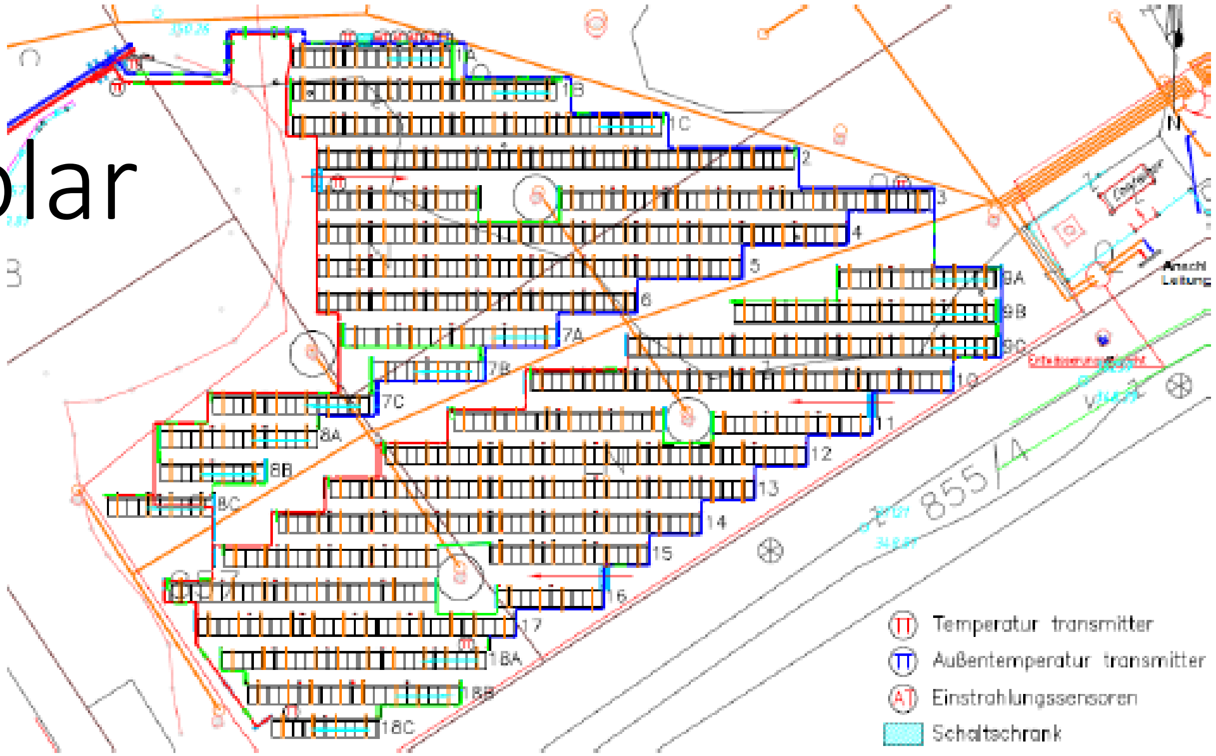
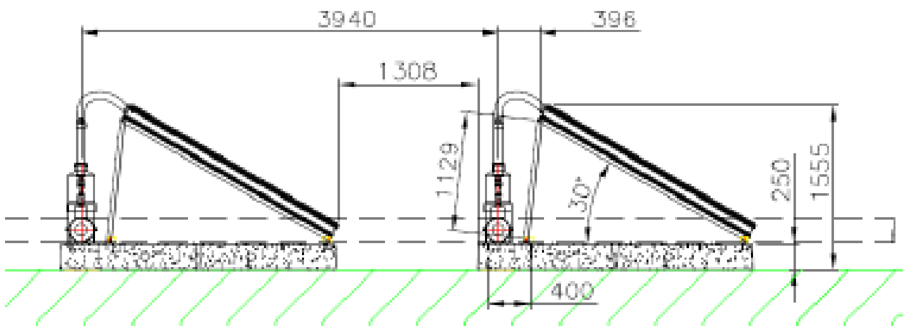


figure: planning collector field



HELIOS, SDH conference Graz, 2018

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4.1 Large Solar

- Specific ST panel systems (~15m^2)
- Systems installed over ground
- Large panel arrays
- Relevant use of land
- Substantial energy savings
- Substantial economic saving
  - Cost of heat ~20-30 €/MWh
  - (vs 40-50 €/MWh with fossil fuels)

4.2 Storage

- SDH without storage
  - Limited to periods with relevant solar input (summer)
  - No production during night periods
  - Sizing limited to summer loads
- Storage
  - Increase solar fraction
  - Heating by night
  - Heating during autumn & Winter
  - Other benefits in peak shaving
    - Can store heat from other producers even without solar input

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4.2 Storage

- Day/week storage
  - Stratified tanks

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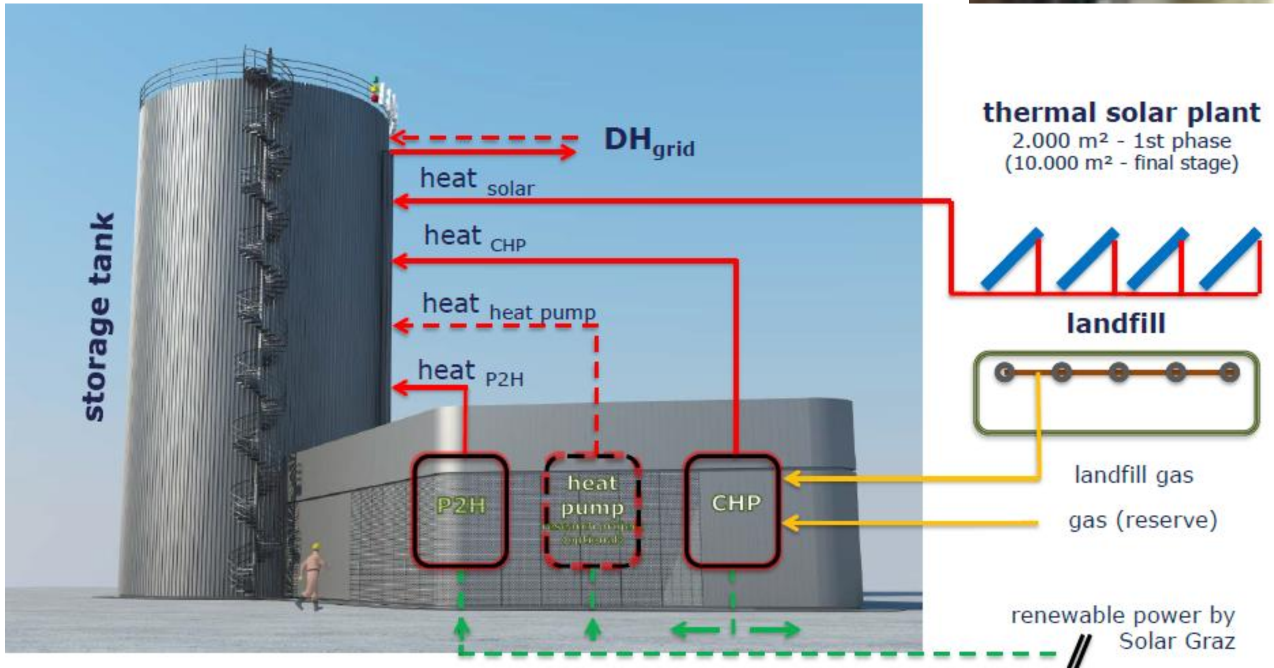

4.2 Storage

- Seasonal storage
  - Pit storage

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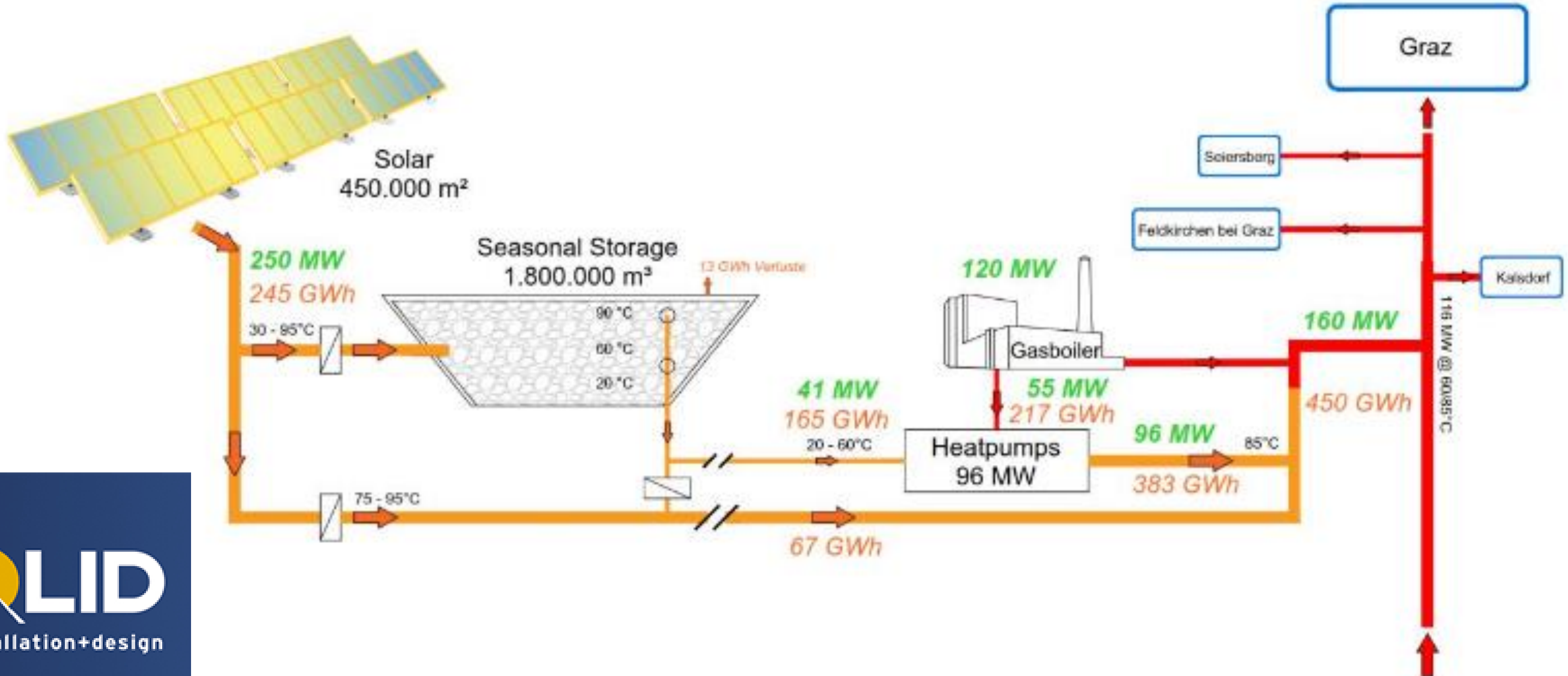
Reference project in progress – Solar district heating:

Feasibility Study BIG Solar Graz



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4.2 Storage

- Seasonal storage
  - Pit storage

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planenergi.eu

Dronninglund District Heating; 37,573 m2 of solar collectors and 62,000 m3 pit heat storage

~$2 m^3/m^2$

ramboll.com

4.2 Storage

- Seasonal storage
  - Pit storage

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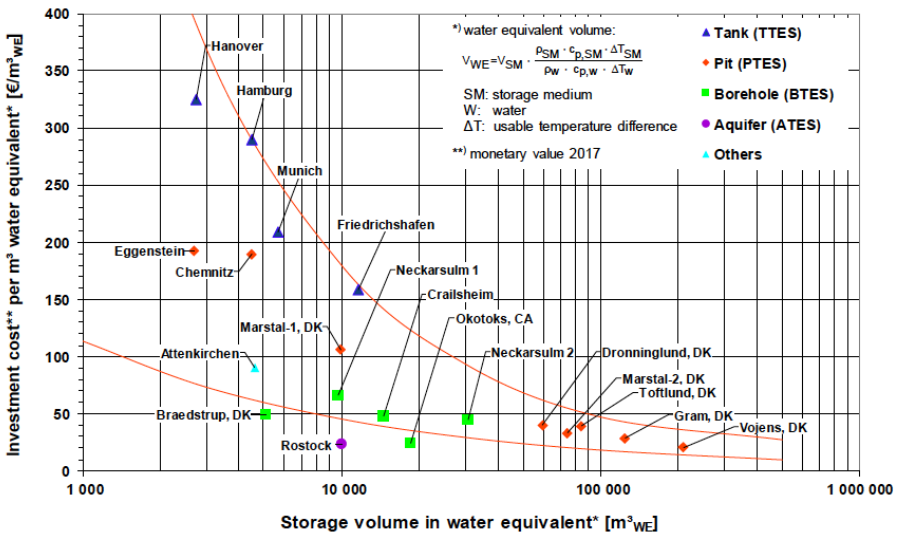
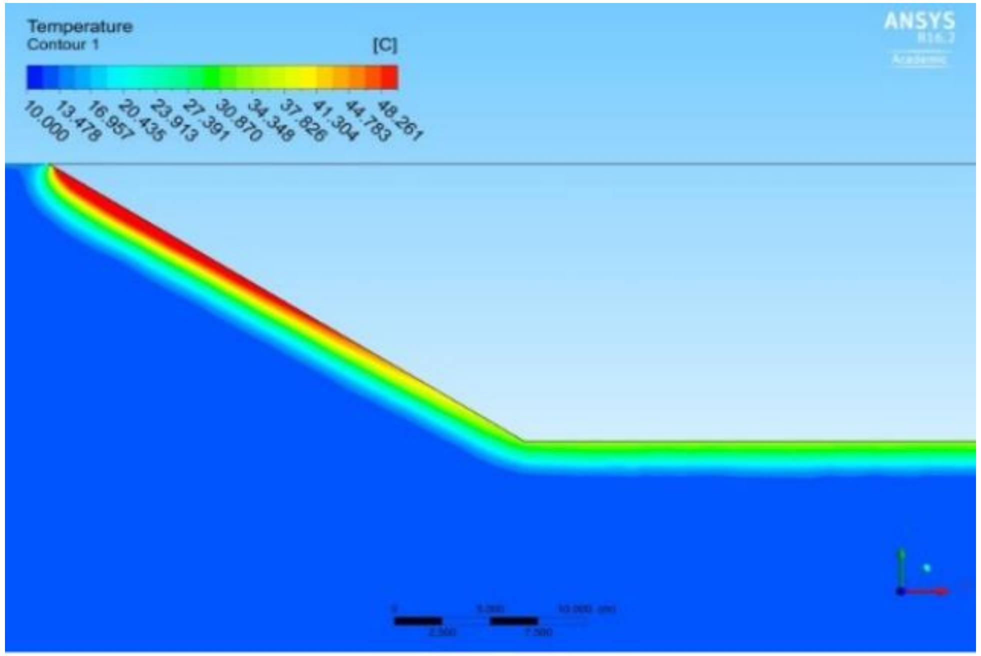


https://www.solarthermalworld.org/news/seasonal-pit-heat-storage-cost-benchmark-30-eurm3



https://backend.orbit.dtu.dk/ws/files/141970828/Untitled_2.pdf

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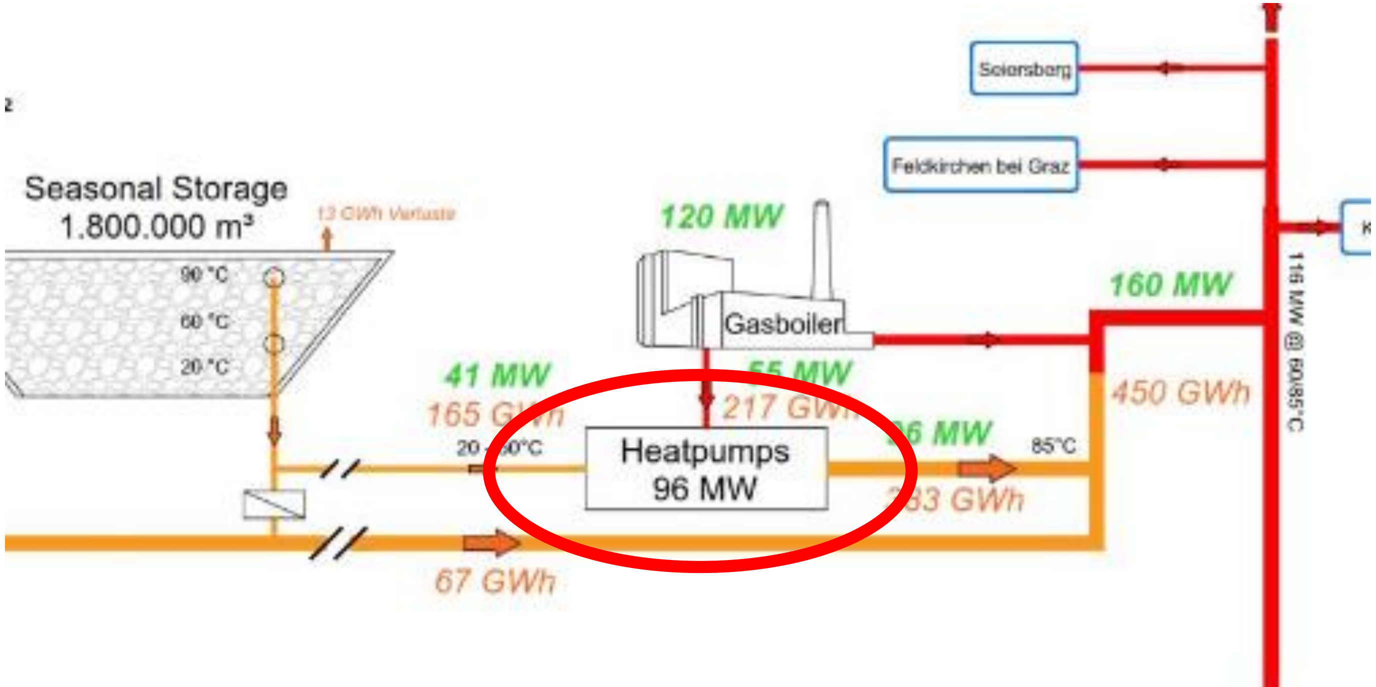
4.2 Storage

- Some tricks with heat pumps
  - Storage temperature not enough (~ by 10-15ºC)
    - Heat pump can be use at VERY LARGE COP
      - Primary-side: storage
      - Secondary-side: DH
    - Increased use of solar heat
  - Tank not sufficiently stratified
    - Heat pump can be used to better stratify tank
      - Primary-side: bottom of tank /outlet to ST
      - Secondary-side: top of tank / inlet from ST
    - Increased performance of ST field (lower inlet T)
    - Increased stratification & better use of heat in DH
  - Storage temperature not enough (~ by 20ºC)
    - Heat can be injected in return line of DH
    - Only in low share (<25% of total load)
    - Only if hydraulic design of network allows

4.2 Storage

- Some tricks with heat pumps
  - Storage temperature not enough (~ by 10-15ºC)
    - Heat pump can be use at VERY LARGE COP
      - Primary-side: storage
      - Secondary-side: DH
    - Increased use of solar heat



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4.2 Storage

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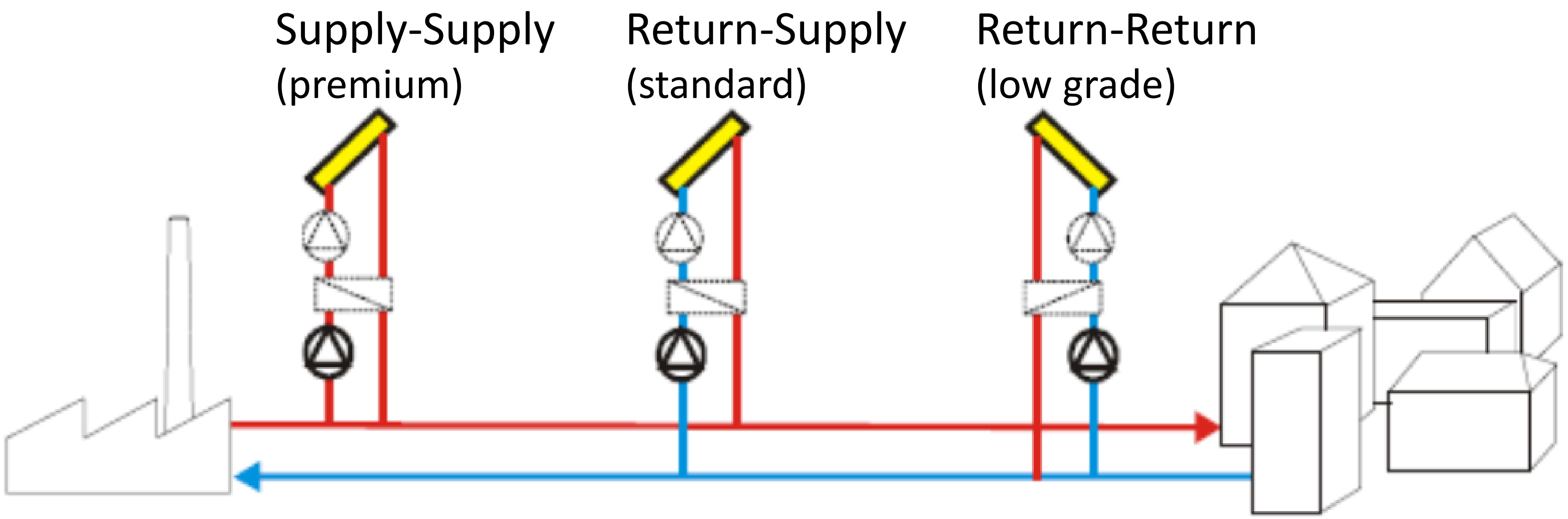

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4.3 Distributed Solar

- Connection of Building Integrated ST systems to DH
- Advantages
  - Greater heat production (than Isolated systems)
  - Lower transmisión loses (than Large Solar)
  - No need for storage (if ST in less tan 1/3 of buildings)
  - Injection in return line substantially increases heat production
  - Maintenance costs can be reduced (compd to Isolated systems) if performed by DH company
  - No need for land (compd to Large Solar)
- Disadvantages
  - More complex & expensive than Large Solar
  - Only small solar fractions are achievable without storage

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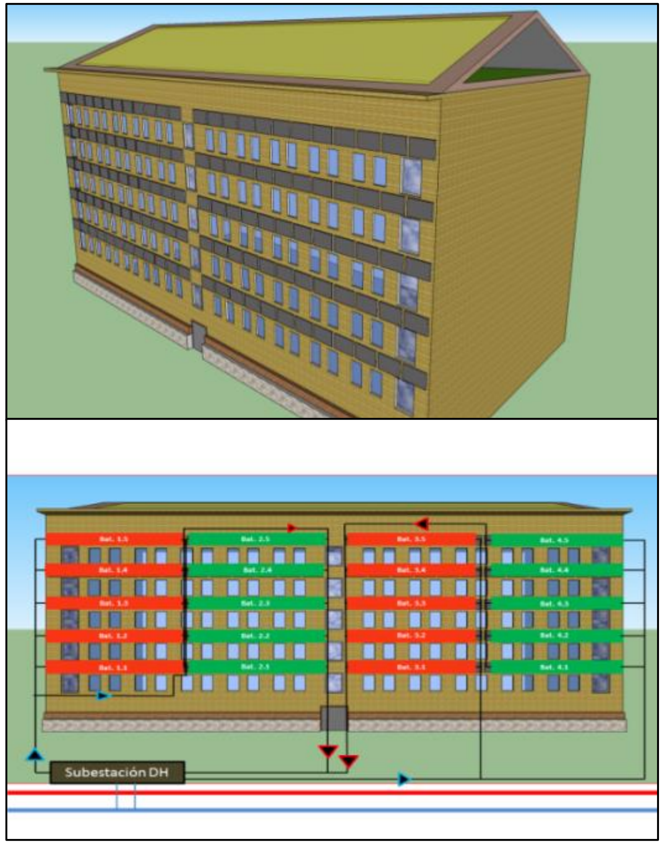
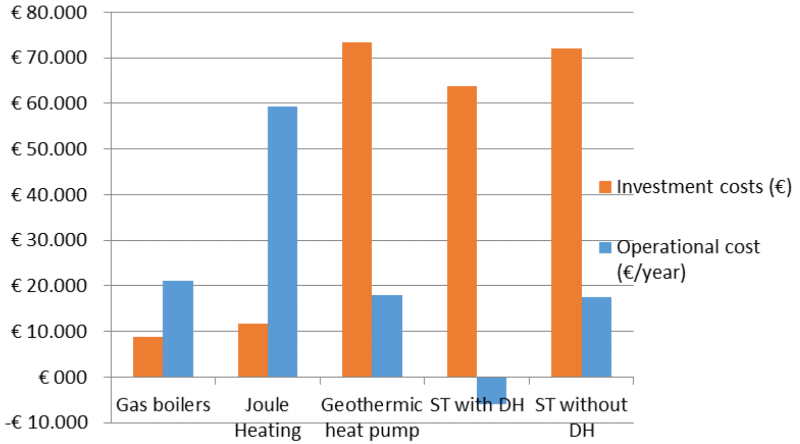
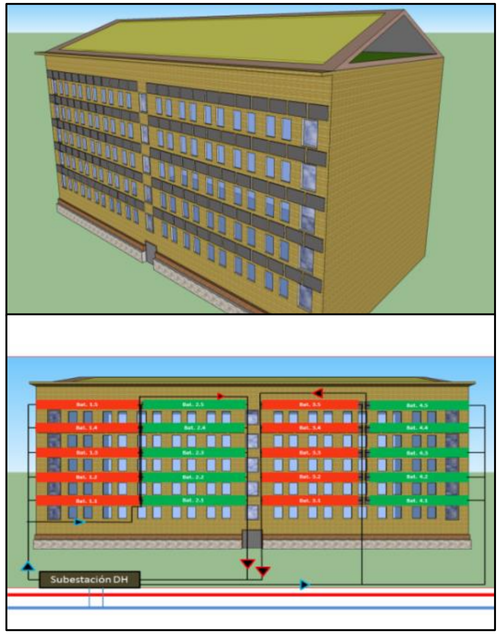
4.3 Distributed Solar

- ST systems in façades
  - (unglazed systems, mainly connected to return line)
- When ST needs to be installed
  - Connection to DH cheaper than isolated systems
  - No need for backup heat source
- Negative Operational costs
  - DH purchases heat at a fraction of DH heat cost





M. Lumbreras, et Al. Unglazed solar thermal systems for building integration, coupled with district heating systems... Journal of Facade Design and Engineering, 2018



4.3 Distributed Solar

- Technical issues to be considered
  - Preliminar study. To be refined
  - Systematic injection in return line
  - Only valid for low solar fractions
  - Only valid for a limited number of connections
- Business issues to be considered
  - Economic performance varies with DH heat price
  - DH operators make their business* on Heat production & Distribution. ¿Will they allow this kind of systems?

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4.3 Distributed Solar

- Integration of ST fields over existing DH networks (2) in Barcelona
- Large ST fields (over factories)
- Connection of Building Integrated ST
- Different DH heat price in each network

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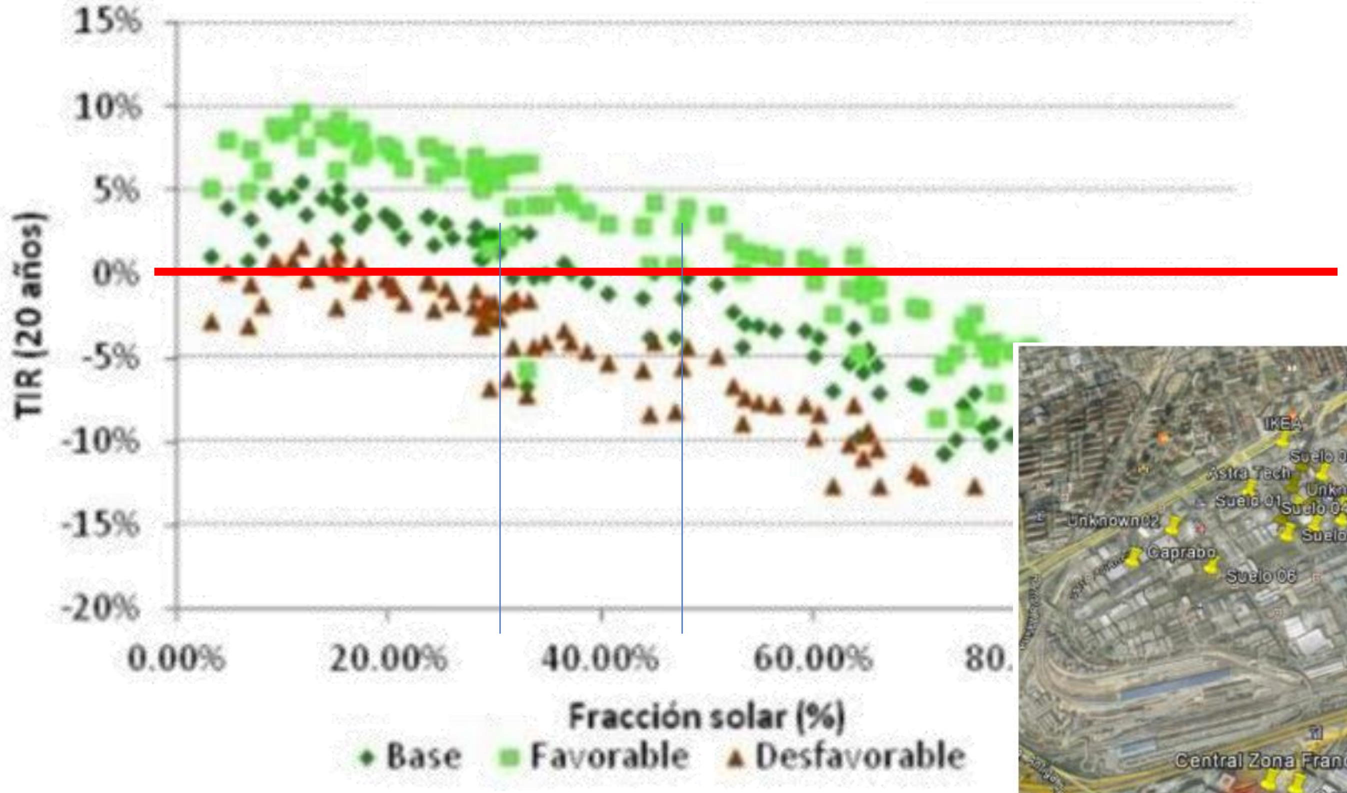
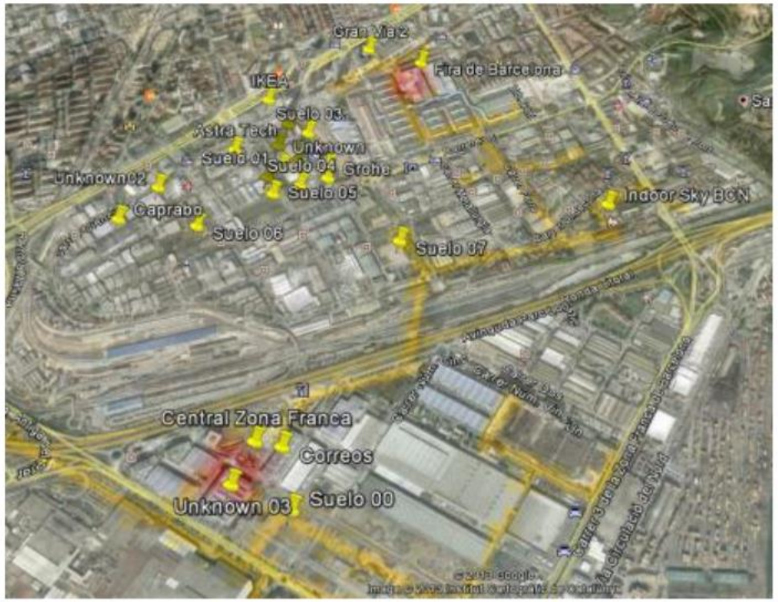
4.3 Distributed Solar

- Large Solar in Ecoenergies network (biomass)
  - Profitable Return on investment if solar fraction <~30 %





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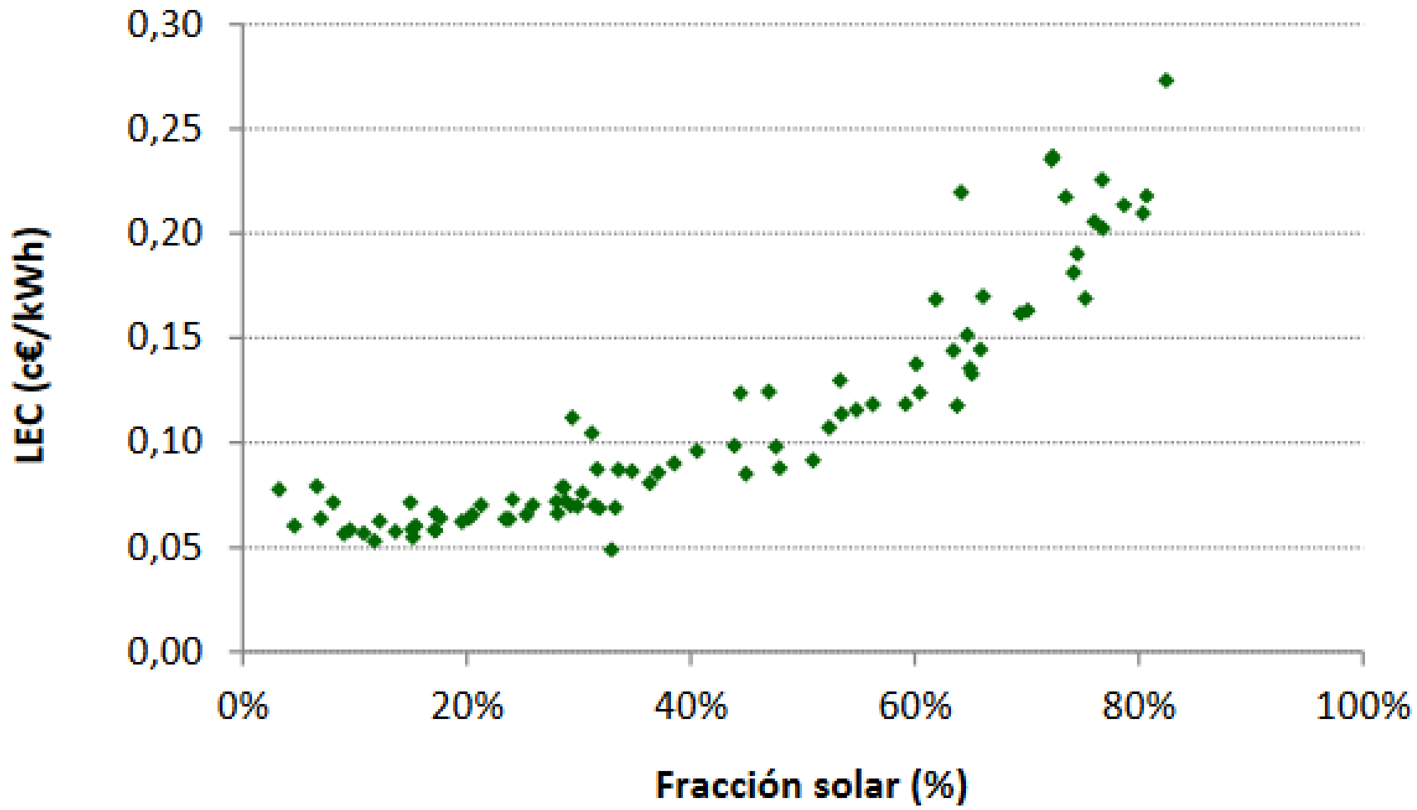
4.3 Distributed Solar

- Large Solar in Ecoenergies network (biomass)
  - Levelized Energy costs increase if Solar Fraction >30-35 %



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4.3 Distributed Solar

- Large Solar in Districlima network (waste incineration)
  - Not profitable due to low cost of heat

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4.3 Distributed Solar

- Building Integrated Solar in Districlima network (waste incineration)
  - Heat production doubles when compared to isolated system

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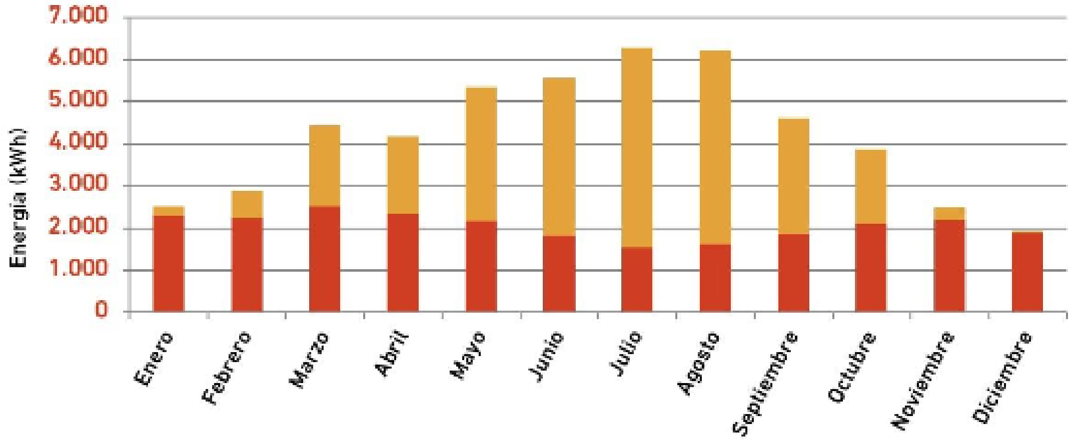
(kWh)	Rad. solar incidente	Producción solar campo	Aport. solar consumo	Aport. solar interna (red interior edificio)	Aport. a red de distrito
TOTAL	128.612	52.879	50.374	24.605	25.769
kWh/m^2	1.644	687	654	320	335



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4.3 Distributed Solar

- Building Integrated Solar in Districlima network (waste incineration)
  - Project costs include only connection to DH
  - Positive internal return rate in many projects
  - (even for low cases with low cost of heat)

Nomenclatura	TIR 20 años
SCH1TIP1CAS1	3,20%
SCH1TIP1CAS2	6,20%
SCH1TIP3CAS1	4,30%
SCH1TIP3CAS2	14,60%
SCH2TIP1CAS1	-
SCH2TIP1CAS2	-
SCH2TIP3CAS1	-
SCH2TIP3CAS2	6,30%
SCH3TIP1CAS1	-
SCH3TIP1CAS2	3,90%
SCH3TIP3CAS1	1,10%
SCH3TIP3CAS2	12,50%

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End of Day 2

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