Herrick Laboratories
PURDUE UNIVERSITY

2016 Purdue Conferences
Compressor Engineering
Refrigeration and Air Conditioning
High Performance Buildings

Heat Pumps Architecture Optimization For Enhanced Medium Temperature Geothermal Heat Use in District Heating

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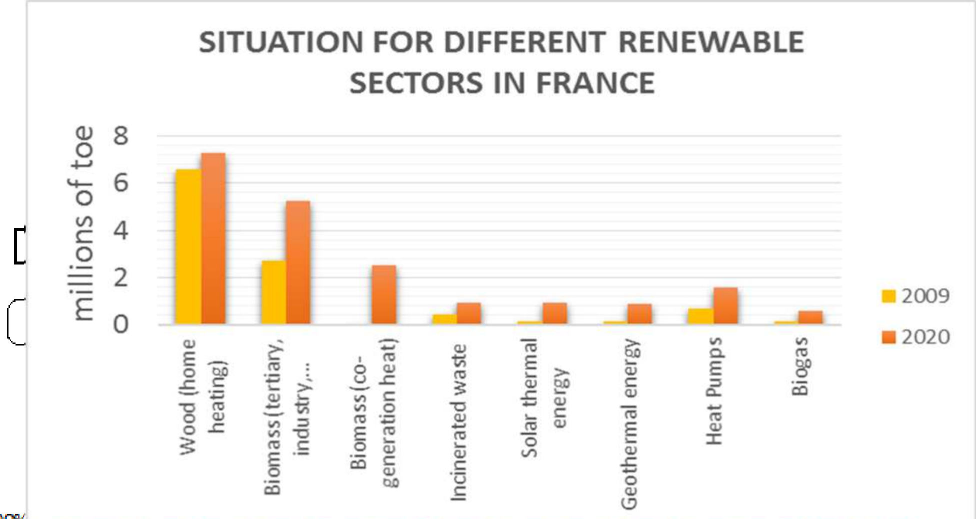
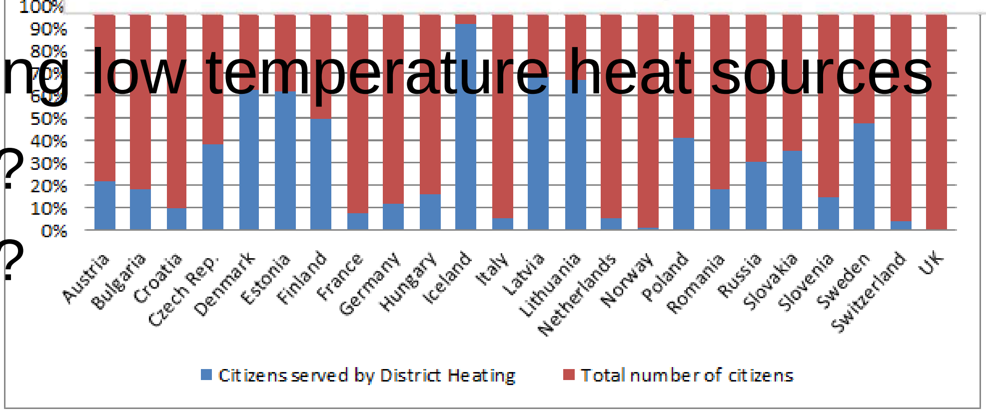
Center for
High Performance
Buildings at Purdue

Context

- District h
  - Urba

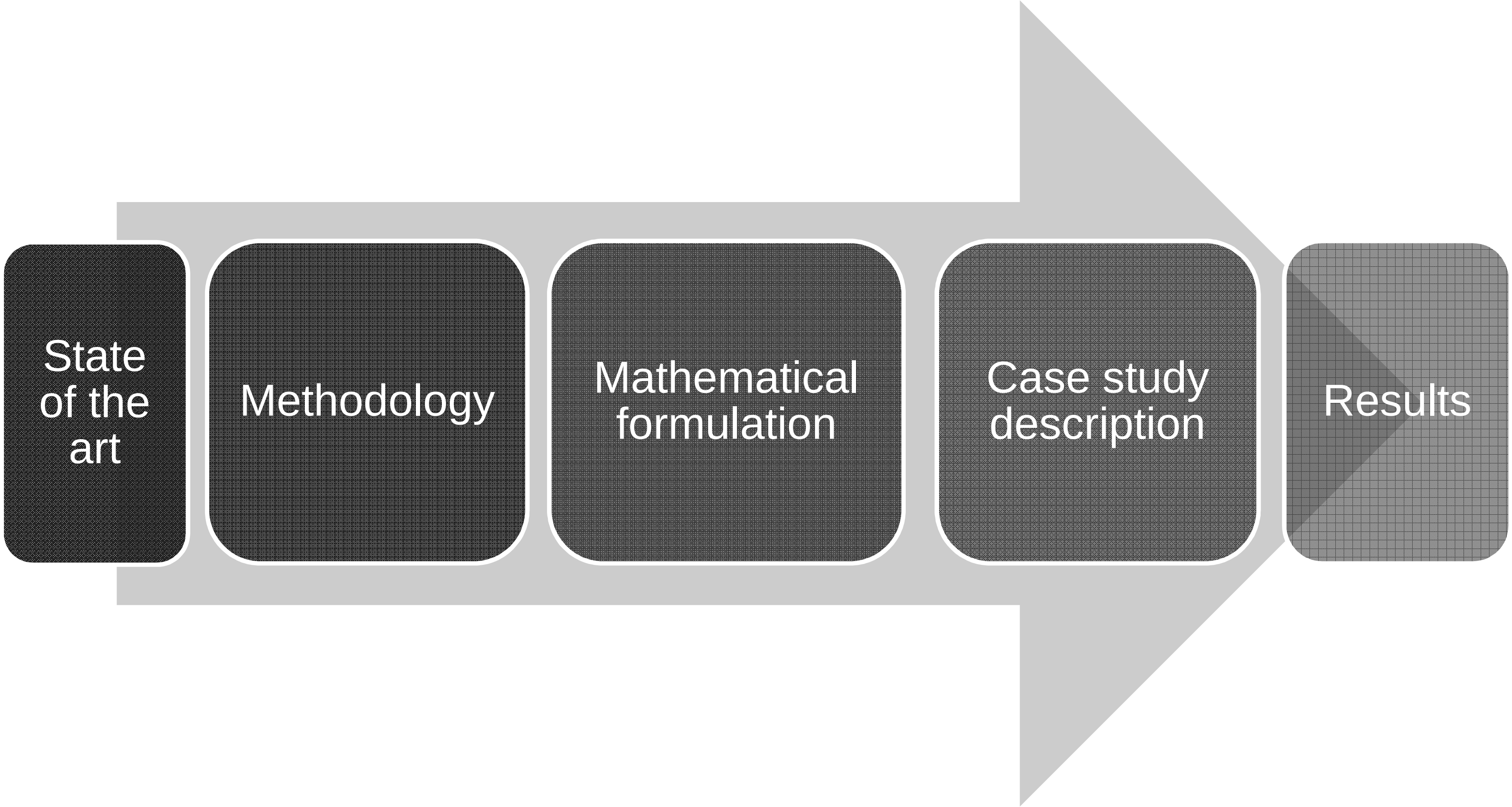




- Valorizing low temperature heat sources
  - Why?
  - How?

➢ **Heat pumps integration in Geothermal Heat Use**

Outline



State of the art

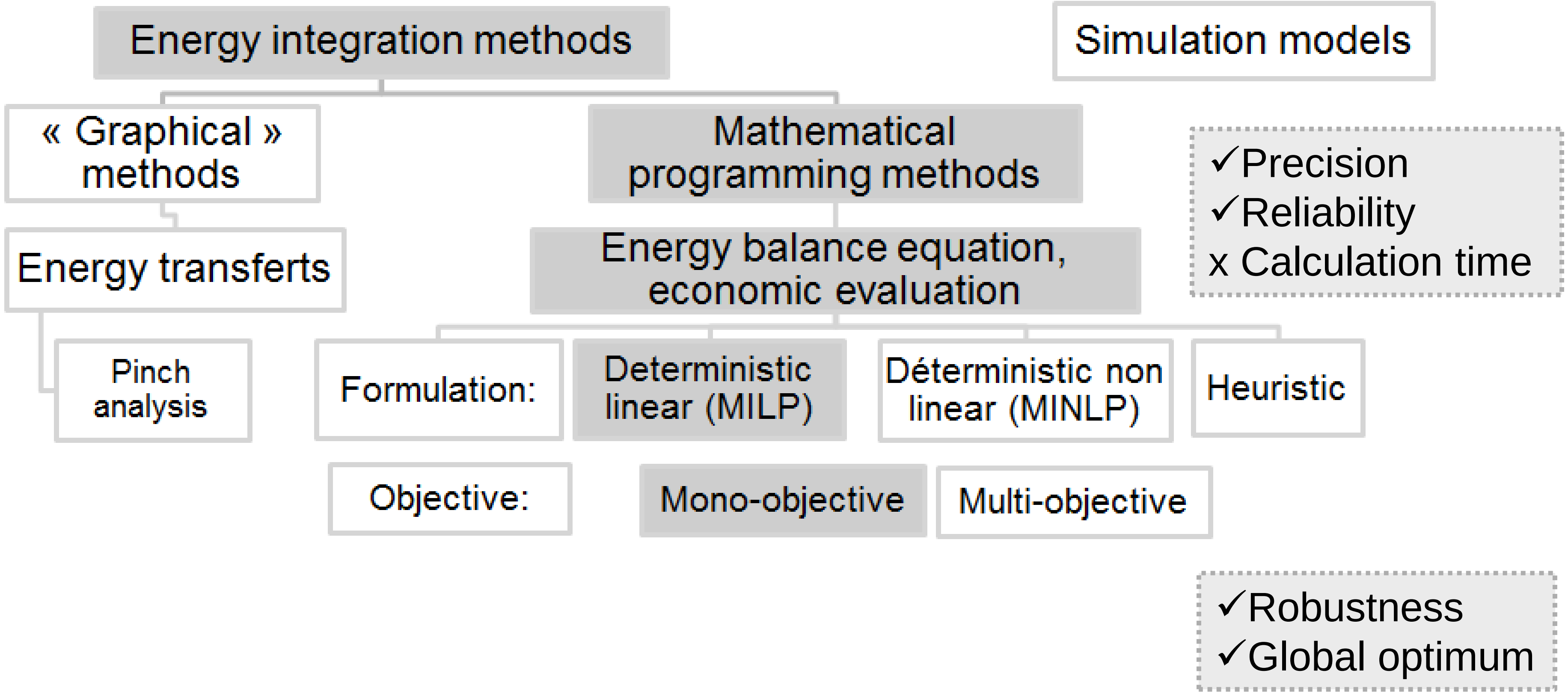
Methodology

Mathematical formulation

Case study description

Results

State of the art



Energy integration methods

« Graphical » methods

Energy transferts

Pinch analysis

Mathematical programming methods

Energy balance equation, economic evaluation

Formulation:

Deterministic linear (MILP)

Déterministic non linear (MINLP)

Heuristic

Objective:

Mono-objective

Multi-objective

Simulation models

✓Precision
✓Reliability
x Calculation time

✓Robustness
✓Global optimum

Key idea / Case study description

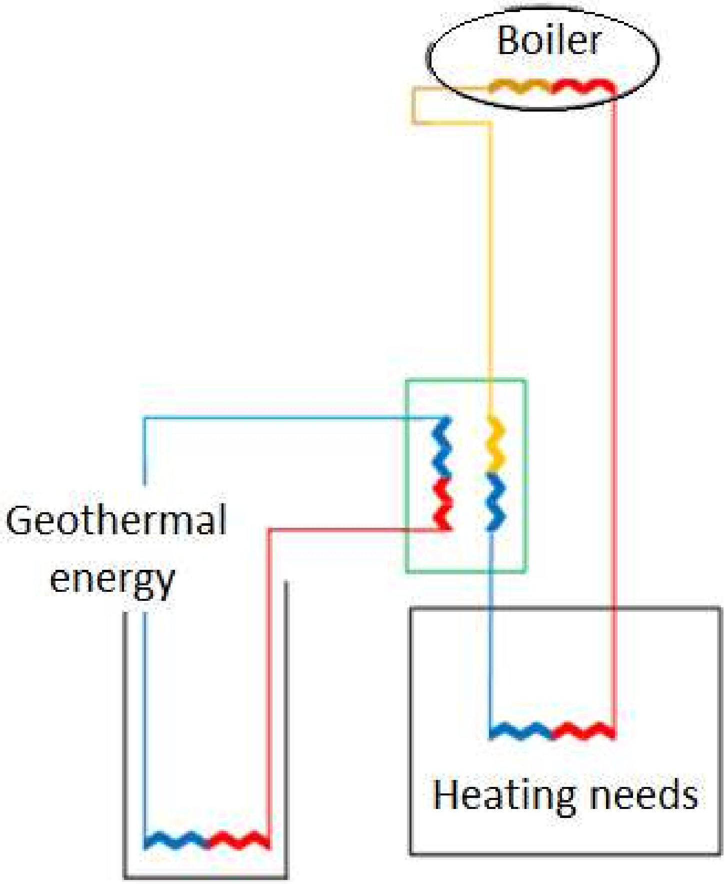
- District heating network
- Available géothermal potential

+

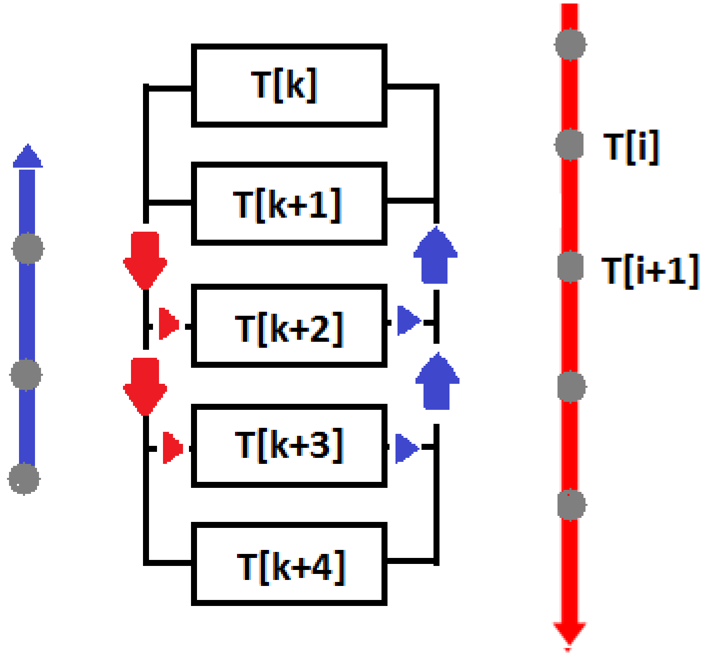
- Minimization of total exergy consumption
- Reduced order modeling for conversion technologies
- MILP in multiperiod

⇩

- Production mix
- Heat pumps architecture (temperature & power)



Mathematical formulation



🟥🟦 Flux

T[k] noeud de température du fluide intérmediaire

T[i] noeud de température des flux

▶▶ débit circulant dans le réseau

Echanges thermiques

Pinch imposed between the intermediate fluid T[k], circulating in the network, and the operating

Law of mass conservation applied to all the heat capacity flows entering or exiting each node «k» in the network at a certain period of time «p».

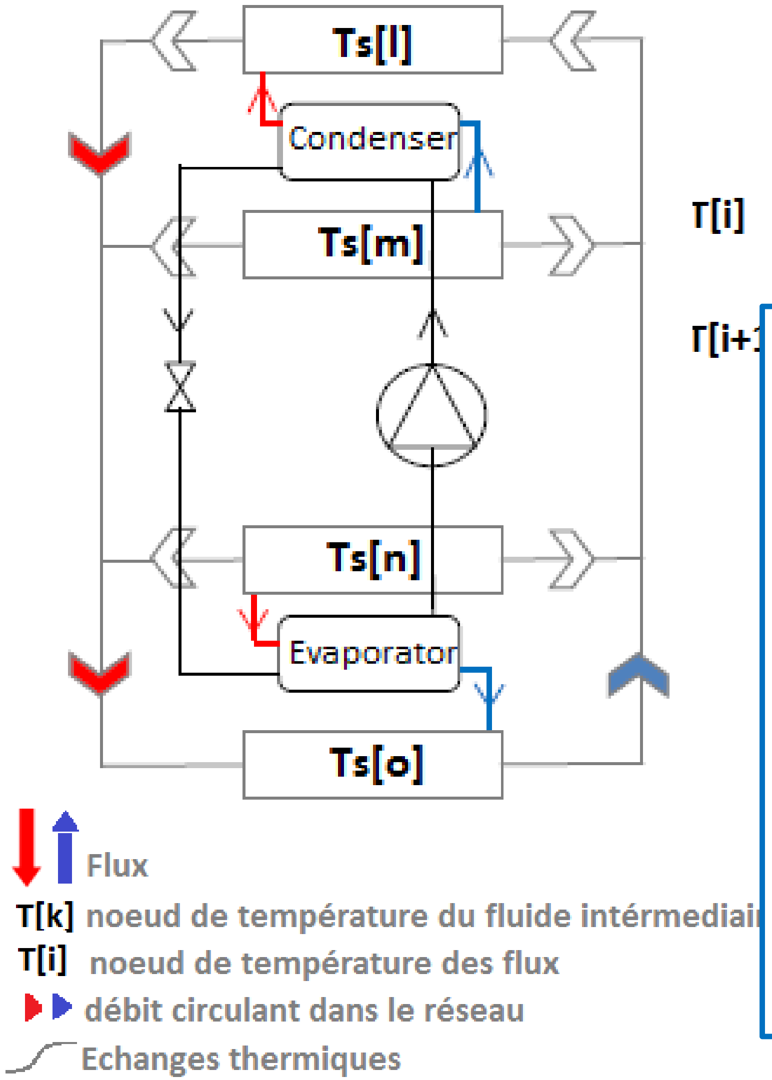
$$Debh_{[k+1,p]} - Debh_{[k,p]} + xh_{[k,p]} = 0$$

are considered after the heat integration of fluxes

$$CP_{C[i,j,p]} \cdot (T_{[i]} - T_{[i+1]}) = \sum_{k=1}^{NS-1} Deb_{f[k,i,j,p]} \cdot (T_{[k]} - T_{[k+1]}) + U_{f[i,j,p]}$$

$$(if \quad T_{[i]} \geq (T_{[k]} + Pinc)\, and \quad T_{[i+1]} \geq (T_{[k+1]} + Pinc))$$

Heat Pump reduced model



Reduced order modeling of the heat pumps, considering their performance in terms of exergy

- Constraint delimiting the number of HP
- Constraint delimiting the maximal compressor power of HP
- HP's COP related to the evaporator's and condenser's power

$$COP_{HP[l,m,n,o,p]} = \eta_{HP} \cdot \frac{Ts_{[l]} + Pinc_{cond,HP}}{(Ts_{[l]} + Pinc_{cond,HP}) - (Ts_{[o]} - Pinc_{evap,HP})}$$

- Compressor's power connected to evaporator's and condenser's power (1st law)

Objective function

Minimize the net heating and cooling demands.

$$\min : Ex_{tot} = \sum Ex_h + Ex_c + Ex_{HP}$$

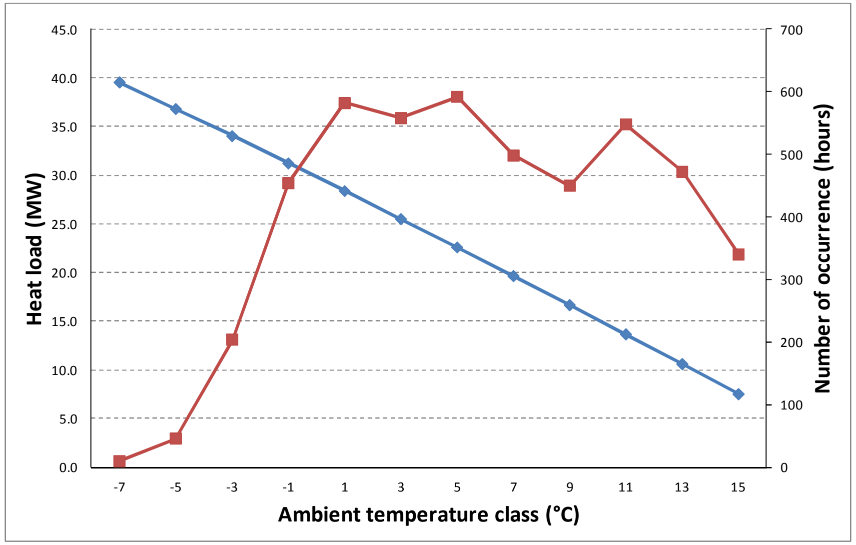
$$Ex_h = \sum_{i=1}^{NT-1} \sum_{p=1}^{t} U_{h[i,p]} \cdot per_{[p]} \cdot \left(1 - \frac{T_{ref}}{T_h}\right)$$

$T_h > T_{ref}$

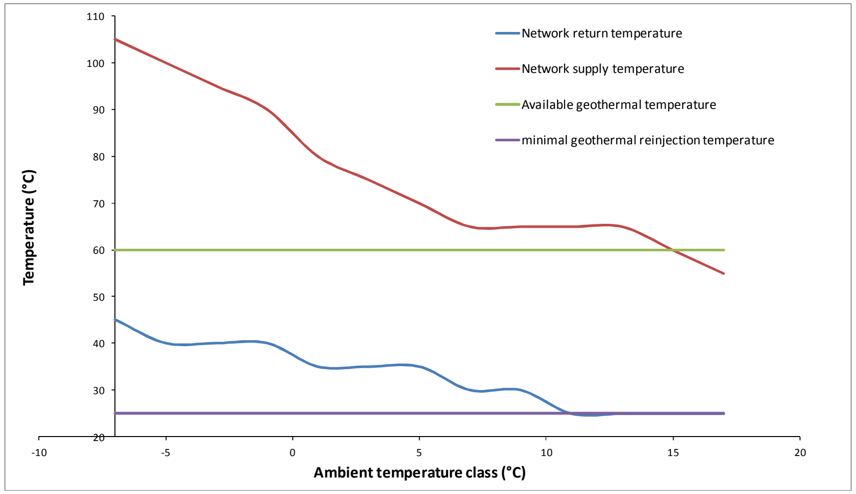
$$Ex_{HP} = \sum_{l=1}^{Ns-2} \sum_{m=l+1}^{Ns-1} \sum_{n=m}^{Ns-1} \sum_{o=n+1}^{NS} \sum_{p=1}^{t} P_{comp[l,m,n,o,p]} \cdot per_{[p]}$$

Application of methodology Assumptions

Network heat demand for different ambient temperature intervals (left scale) and temperature occurrences



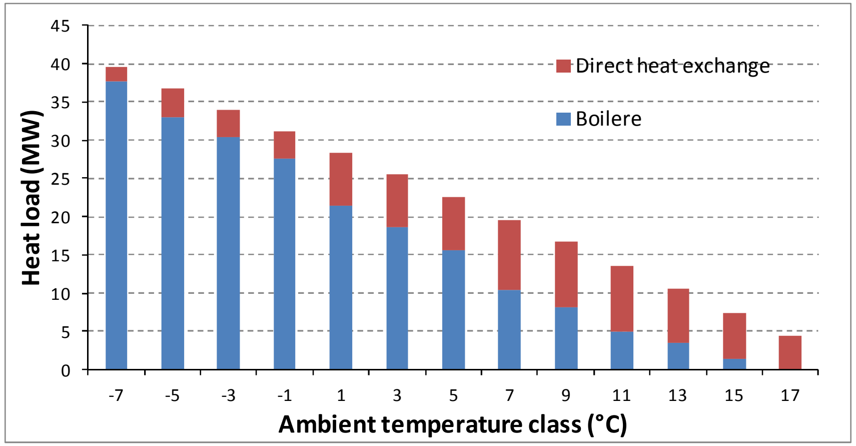
Network operating conditions and geothermal potential



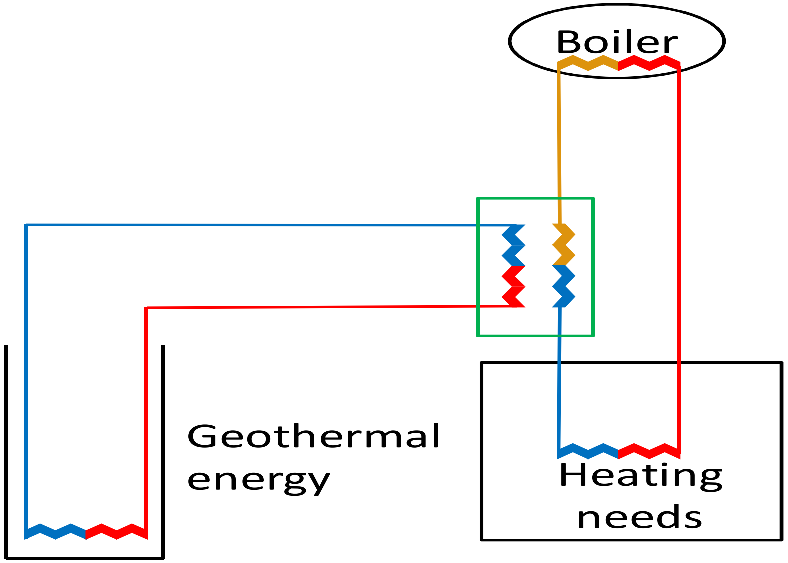
Maximization of the use of an available geothermal potential

Reference case

Reference case heat generation share



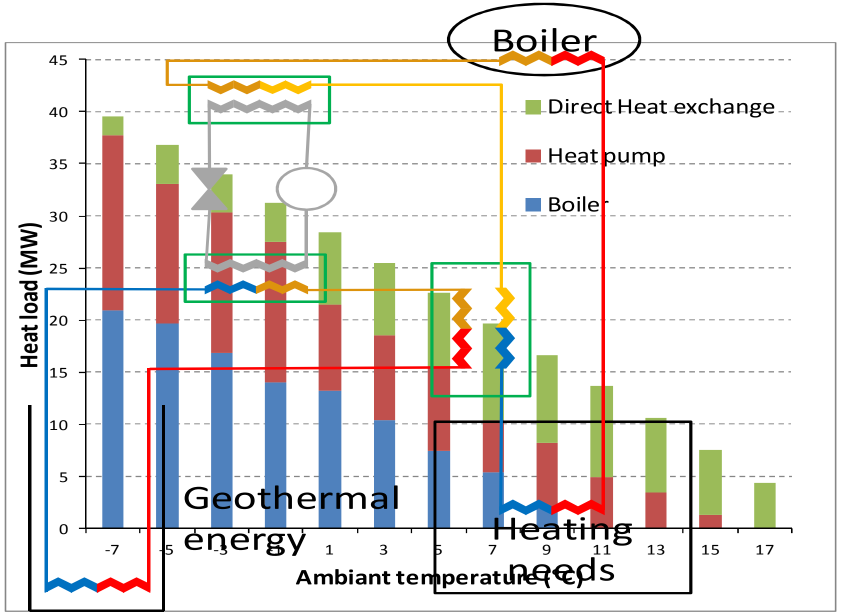
The network's configuration for reference situation



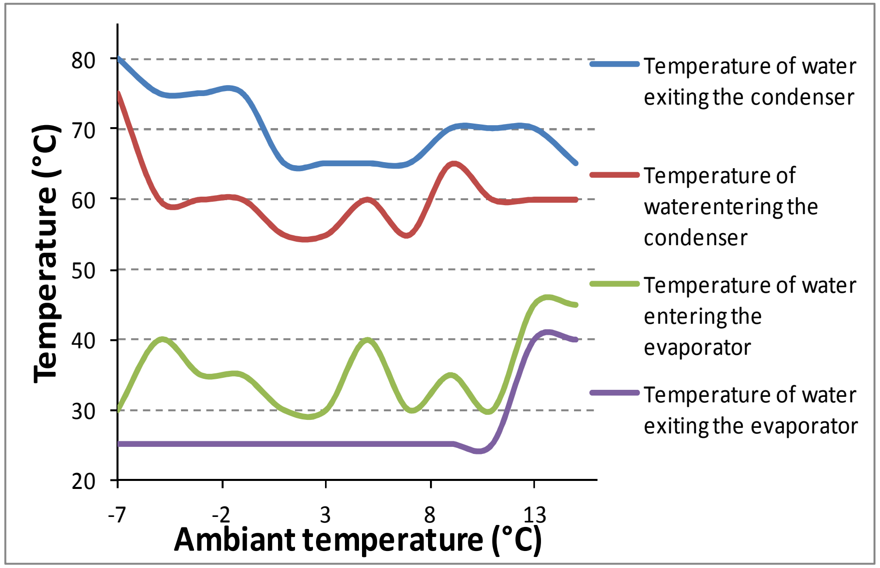
Total heat (MWh)	Gas boiler heat (MWh)	Goethermal heat (MWh)	Geothermal max potential (MWh)	Geothermal use rate	Geothermal to total ratio
117 211	66 385	50 826	113 880	44.6%	43.4%

Heat pumps integration scenarios (1)

Heat load distribution for the first scenario

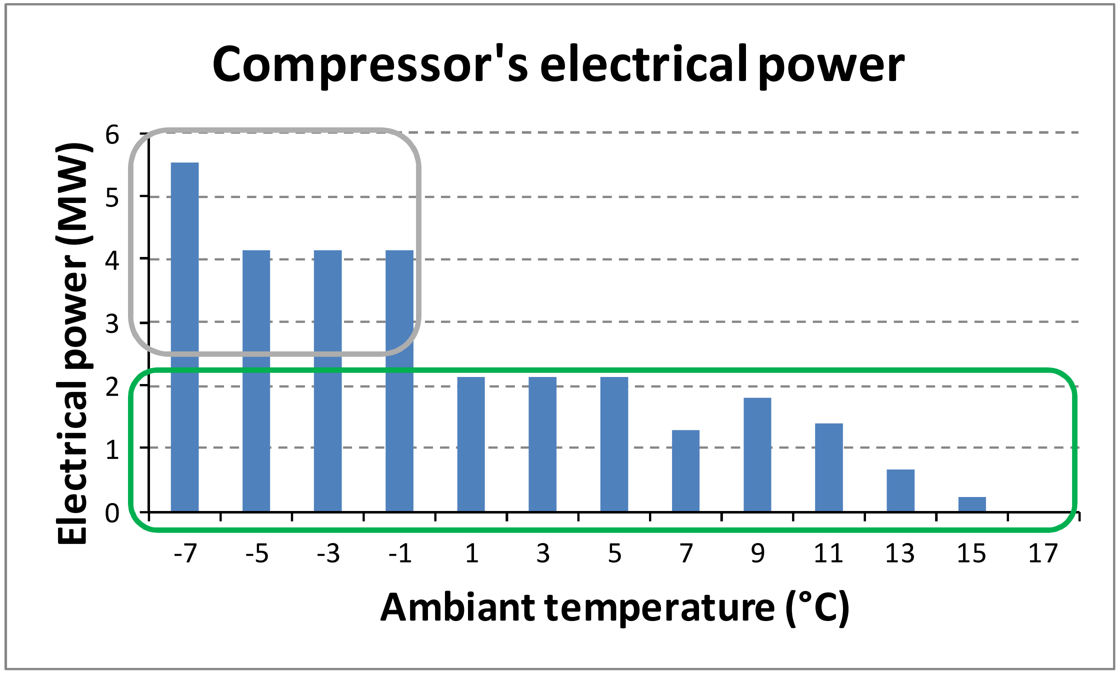


The operating temperatures at the heat pump's exchangers for the first scenario



Total heat (MWh)	Gas boiler heat (MWh)	Goethermal direct heat (MWh)	Condenser heat (MWh)	Geothermal use rate	Geothermal to total ratio
117 211	32 355	50 826	34 030	66.3 %	64.46 %

Heat pumps integration scenarios (1)

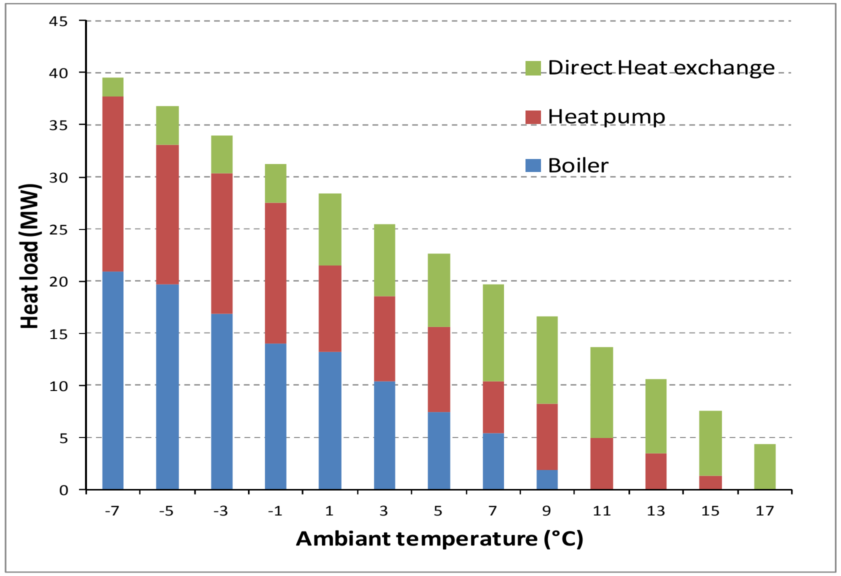


HP's architecture
HP placed in parallel
Operating range between 50 and 100% of nominal

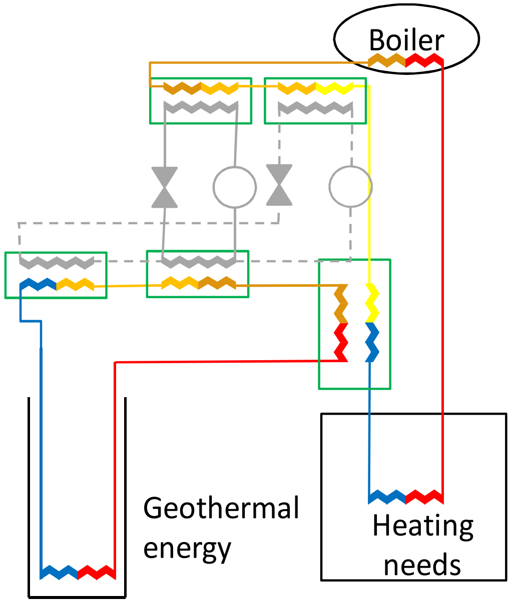
Variation of the heat pump's electrical consumption

Heat pumps integration scenarios (2)

Heat load distribution for the second scenario



Architecture for the HP’s integration for the second scenario



Total heat (MWh)	**Gas boiler heat (MWh)**	**Goethermal direct heat (MWh)**	**Condenser heat (MWh)**	**Geothermal use rate**	**Geothermal to total ratio**
117 211	34210	50 826	32 175	66.5 %	64.65 %

Synthesis of results

Case	Total heat (MWh)	Gas boiler heat (MWh)	Goethermal heat (MWh)	Condenser's heat (MWh)	Geothermal use rate	Geothermal to total ratio	COP
Reference	117 211	66 385	50 826	-	44.6%	43.4%	-
1 HP	117 211	32 355	50 826	34 030	66.3 %	64.46 %	3.66
2 HP	117 211	34210	50 826	32 175	66.5 %	64.65 %	4.45

Conclusions
Increase in the share of geothermal energy used
Upgrade of geothermal energy
Share of gas based heat reduced (56.6% to 27.6%)
Higher seasonal COP with an additional HP

Further developments
Detailed design of the heat pumps
Economical evaluation

Thank you

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