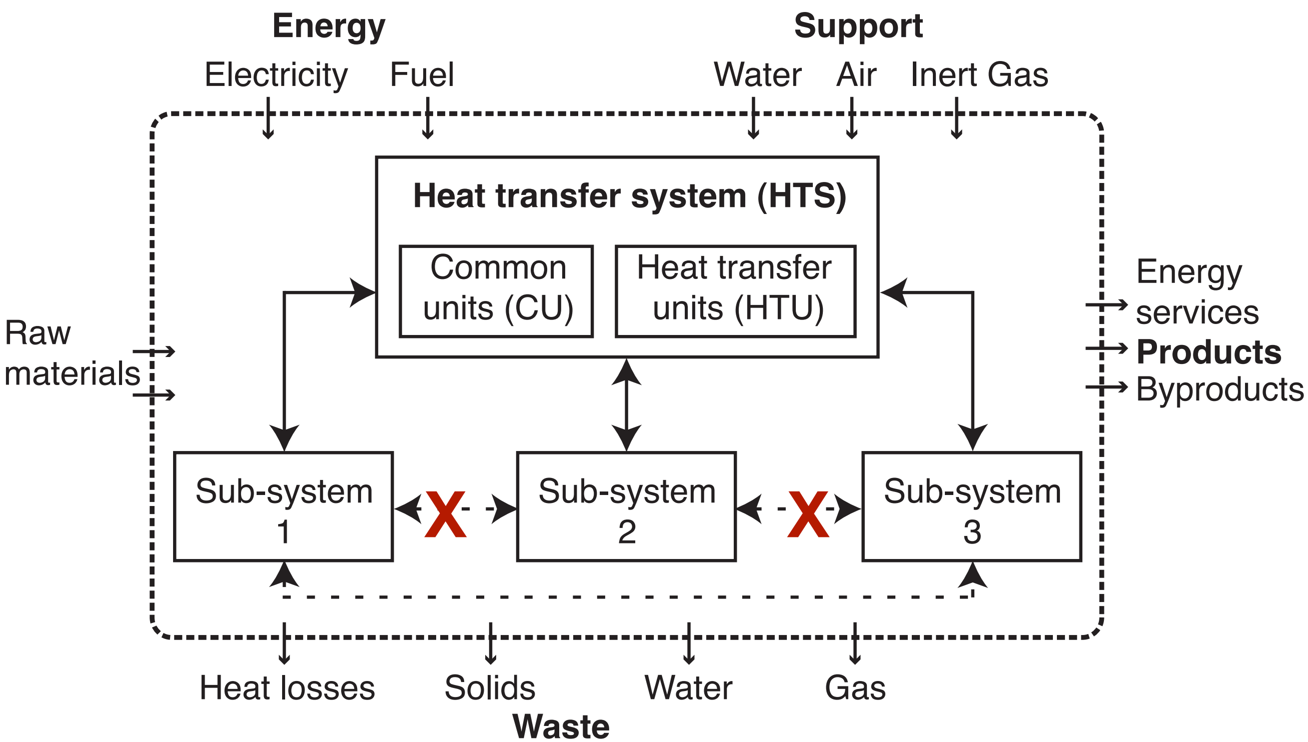
Restricted matches for process system integration

Heat transfer restriction

Yes but : Sub-systems can not exchange heat (directly)



1 Becker H. and Maréchal F., 2011, Energy integration of industrial sites with heat exchange restrictions, Computers and Chemical Engineering, doi:10.1016/j.compchemeng.2011.09.014.

Modifying the heat cascade model

Objective function

$$F_{obj} = min(d \cdot (\sum_{f=1}^{nf}(c_f^+ \sum_{u=1}^{nu} \boldsymbol{f_u} \dot{E}_{f,u}^+) + c_{el}^+ \dot{\boldsymbol{E}}_{\boldsymbol{el}}^+ - c_{el}^- \dot{\boldsymbol{E}}_{\boldsymbol{el}}^- + \sum_{u=1}^{nu} \boldsymbol{f_u} c_u))$$

Heat cascade

$$\sum_{h_k=1}^{ns_{h,k}} \boldsymbol{f_u} \dot{Q}_{h,k,u} - \sum_{c_k=1}^{ns_{c,k}} \boldsymbol{f_u} \dot{Q}_{c,k,u} + \dot{\boldsymbol{R}}_{\boldsymbol{k+1}} - \dot{\boldsymbol{R}}_{\boldsymbol{k}} = 0 \quad \forall k = 1..., nk$$

$$\dot{\boldsymbol{R}}_{\boldsymbol{1}} = 0 \quad \dot{\boldsymbol{R}}_{\boldsymbol{nk+1}} = 0 \qquad \dot{\boldsymbol{R}}_{\boldsymbol{k}} \geq 0 \quad \forall k = 2..., nk$$

Electricity consumption / production

$$\sum_{u=1}^{nu} \boldsymbol{f_u} \dot{E}_{el,u}^+ + \dot{\boldsymbol{E}}_{\boldsymbol{el}}^+ - \sum_{u=1}^{nu} \boldsymbol{f_u} \dot{E}_{el,u}^- \geq 0$$

$$\sum_{u=1}^{nu} \boldsymbol{f_u} \dot{E}_{el,u}^+ + \dot{\boldsymbol{E}}_{\boldsymbol{el}}^+ - \dot{\boldsymbol{E}}_{\boldsymbol{el}}^- - \sum_{u=1}^{nu} \boldsymbol{f_u} \dot{E}_{el,u}^- = 0$$

$$\dot{\boldsymbol{E}}_{\boldsymbol{el}}^+ \geq 0 \qquad \dot{\boldsymbol{E}}_{\boldsymbol{el}}^- \geq 0$$

Multiplication factors

$$\boldsymbol{y_u} \cdot f_u^{min} \leq \boldsymbol{f_u} \leq \boldsymbol{y_u} \cdot f_u^{max}$$

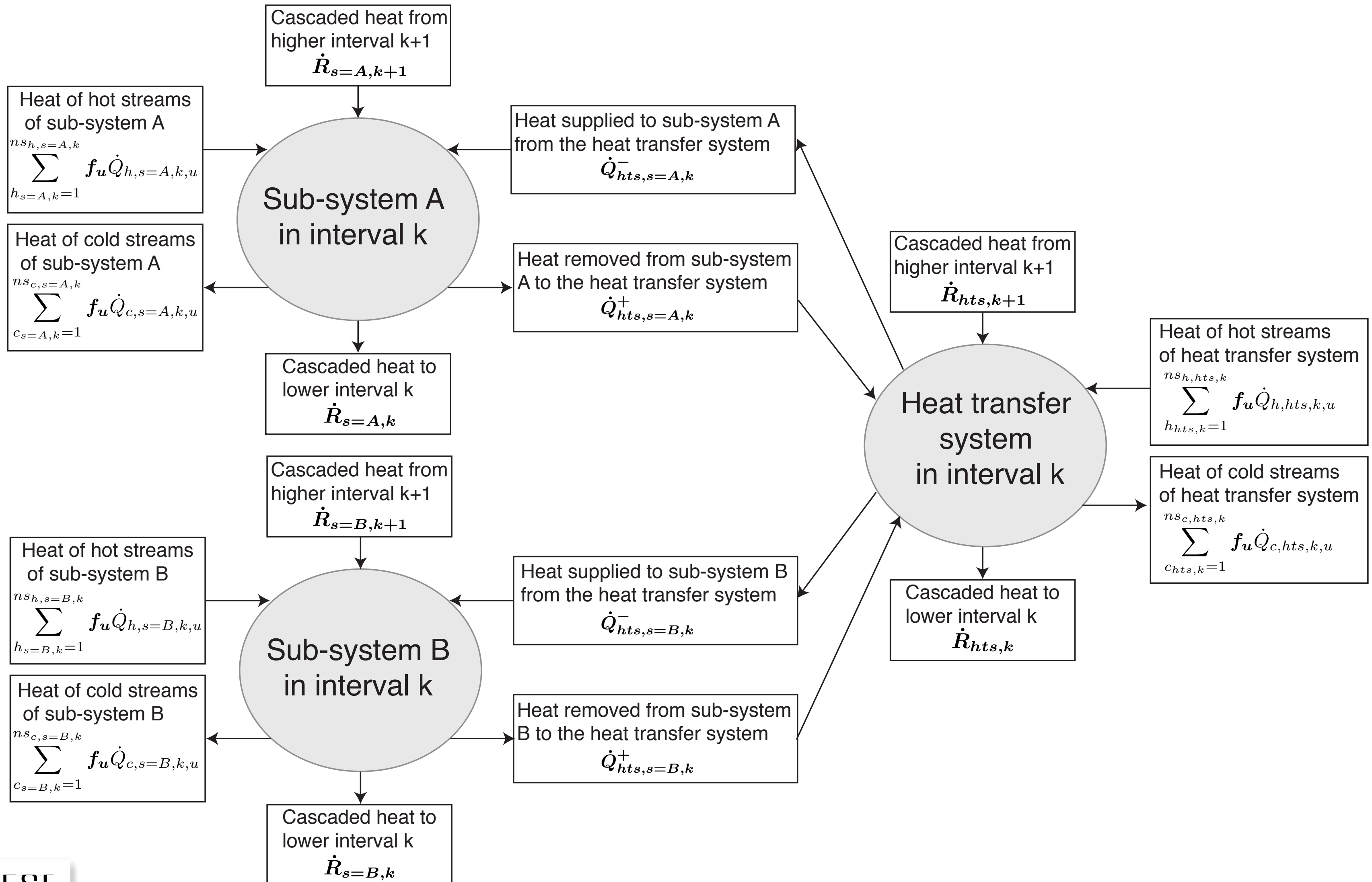
- **Heat transfer constraints ?**

⇩

- **Modification of the heat cascade**

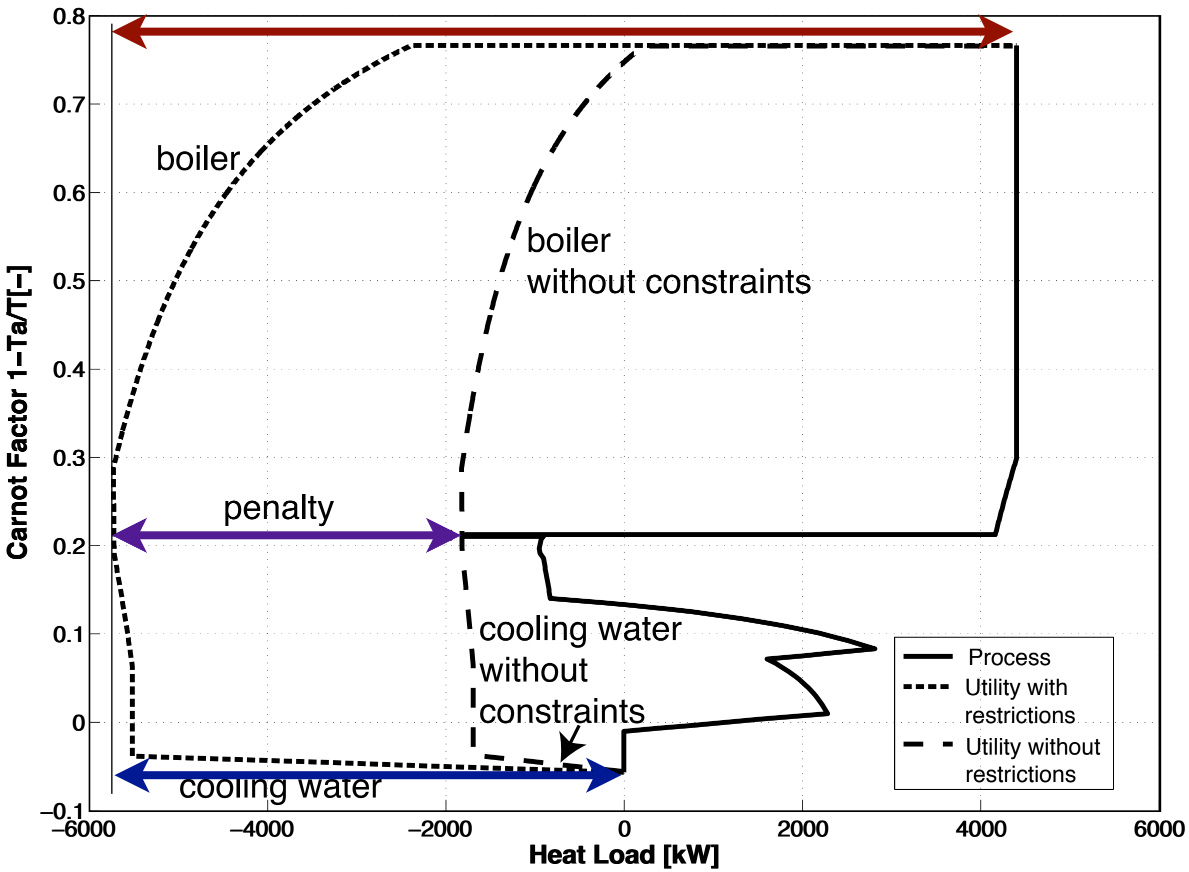
Heat cascade modifications

MILP model => minimize the penalty of the constraints



Energy penalty due to restricted matches

Do you accept the penalty ?



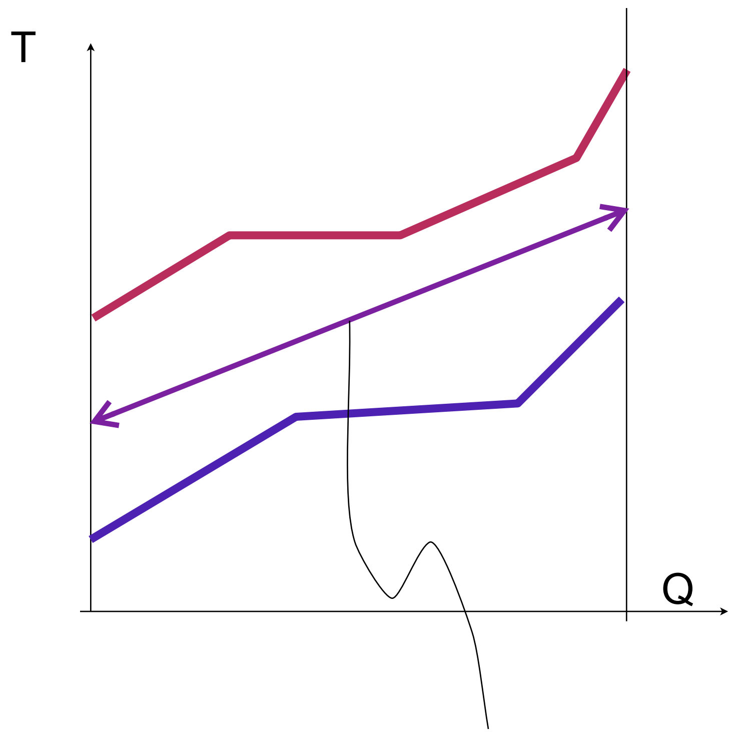
Without constraints

Hot utility	6014 kW
Cold utility	1651 kW

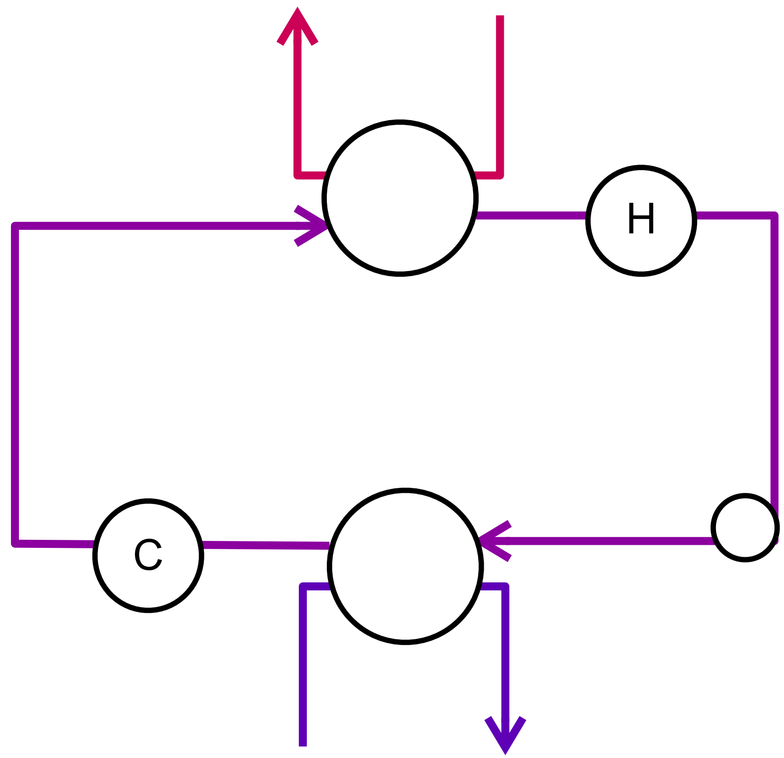
With constraints

Hot utility	9868 kW
Cold utility	5505 kW
Penalty	3854 kW

Introduce heat transfer fluid

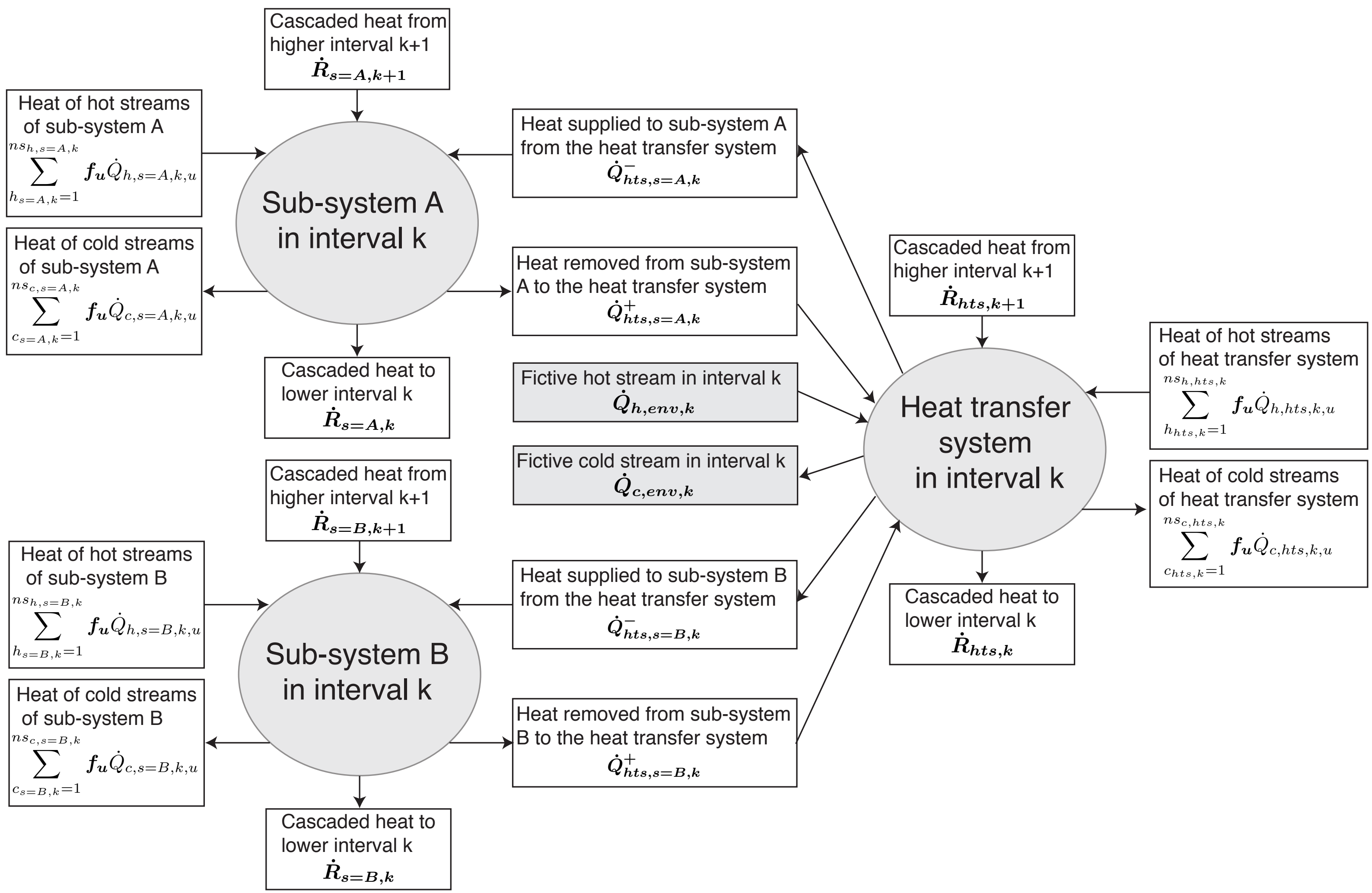


Temperature levels ?

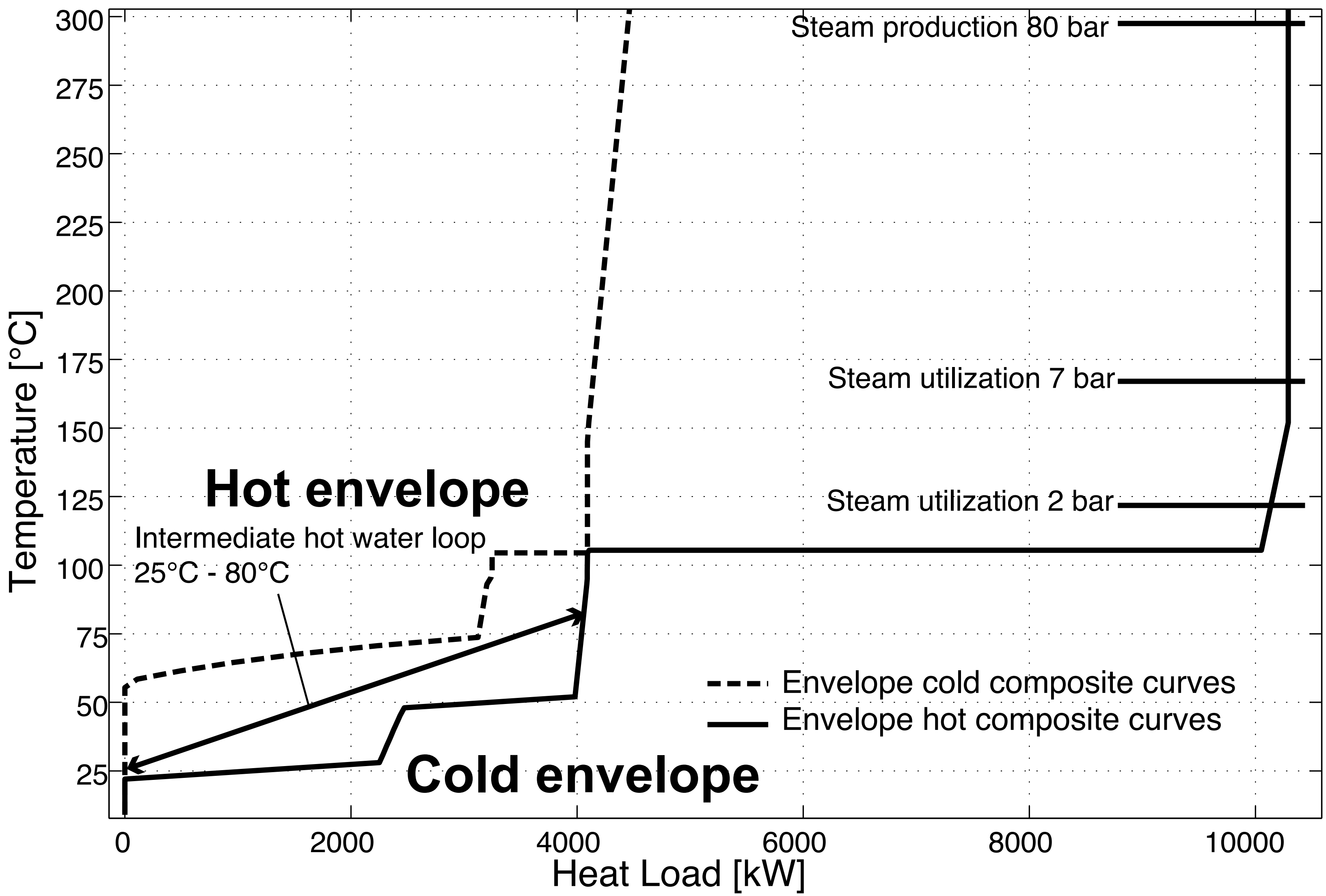


2 Heat exchangers
Higher DTmin
Flexibility

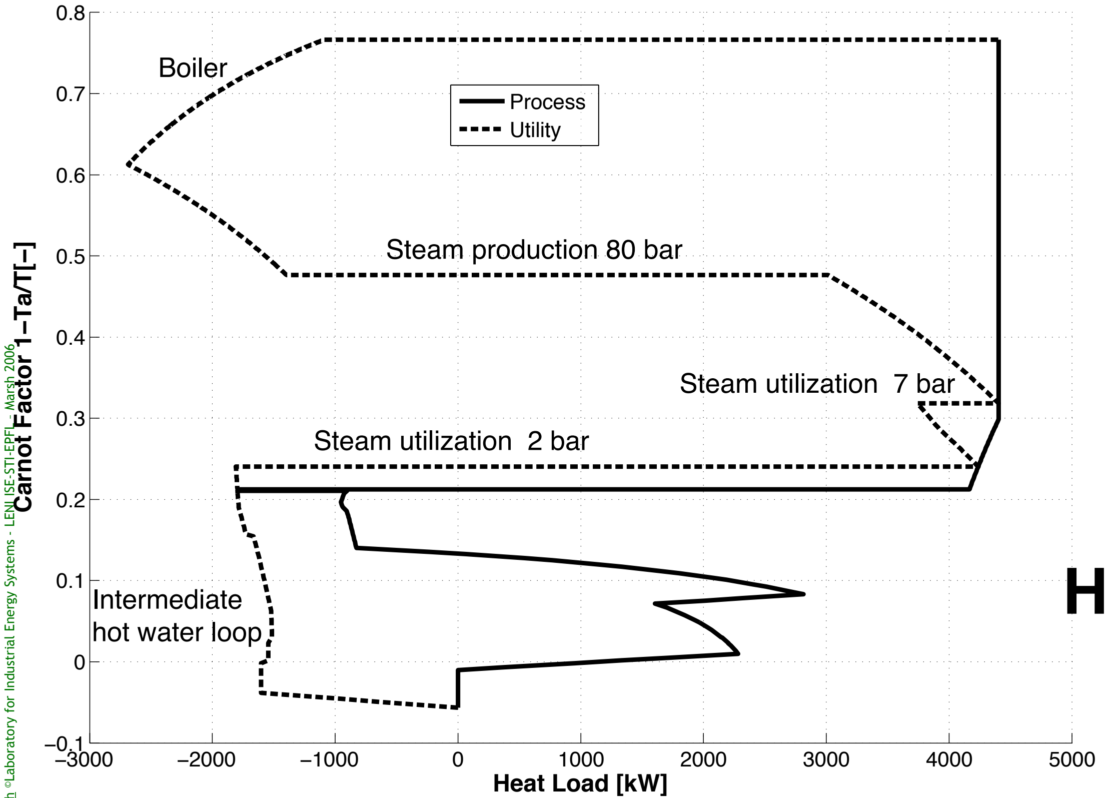
Intermediate heat transfer units - envelope curves



Envelope composite for heat transfer fluid selection



Integration of intermediate heat transfer units



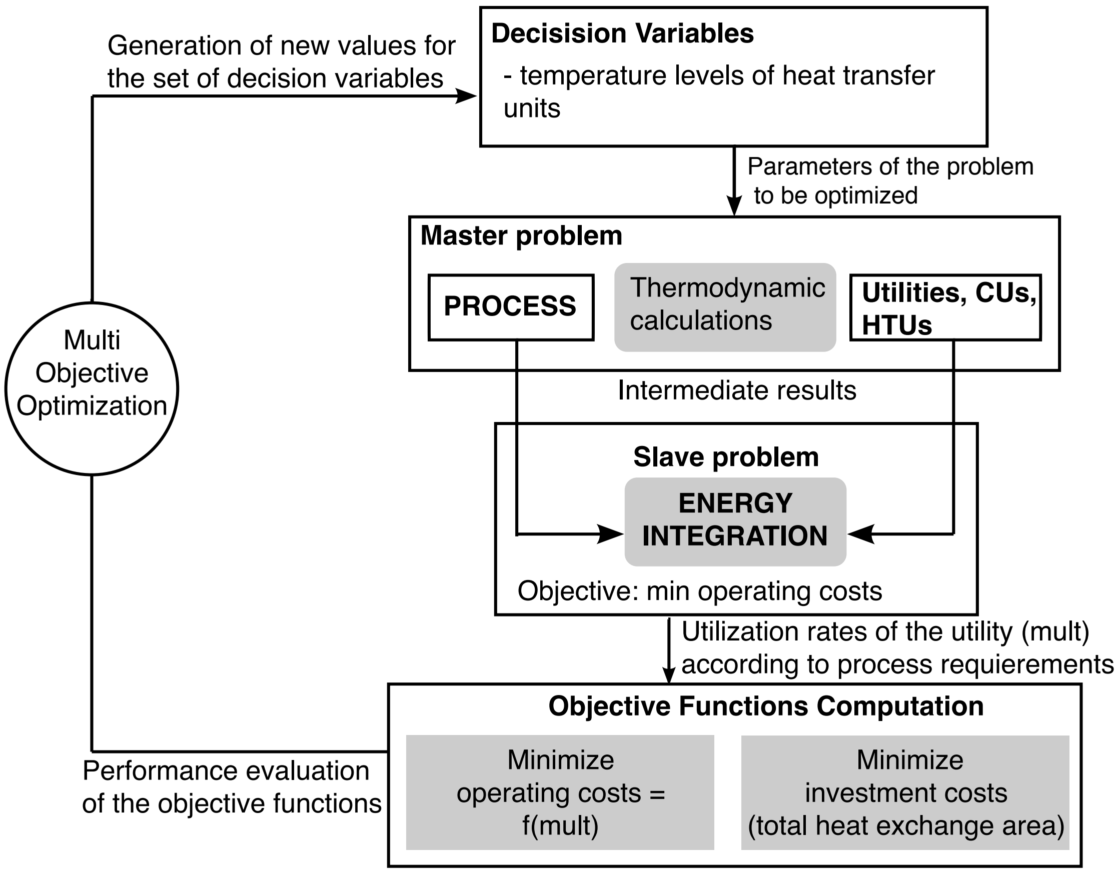
Heat transfer constraints

- Heat recovery
- Heat transfer fluid flows
- Cogeneration
  - Steam network
- **Heat pumps as a heat transfer fluid**

Heat transfer constraints

- LP formulation
- Easier HEN design
- Multi-level constraints

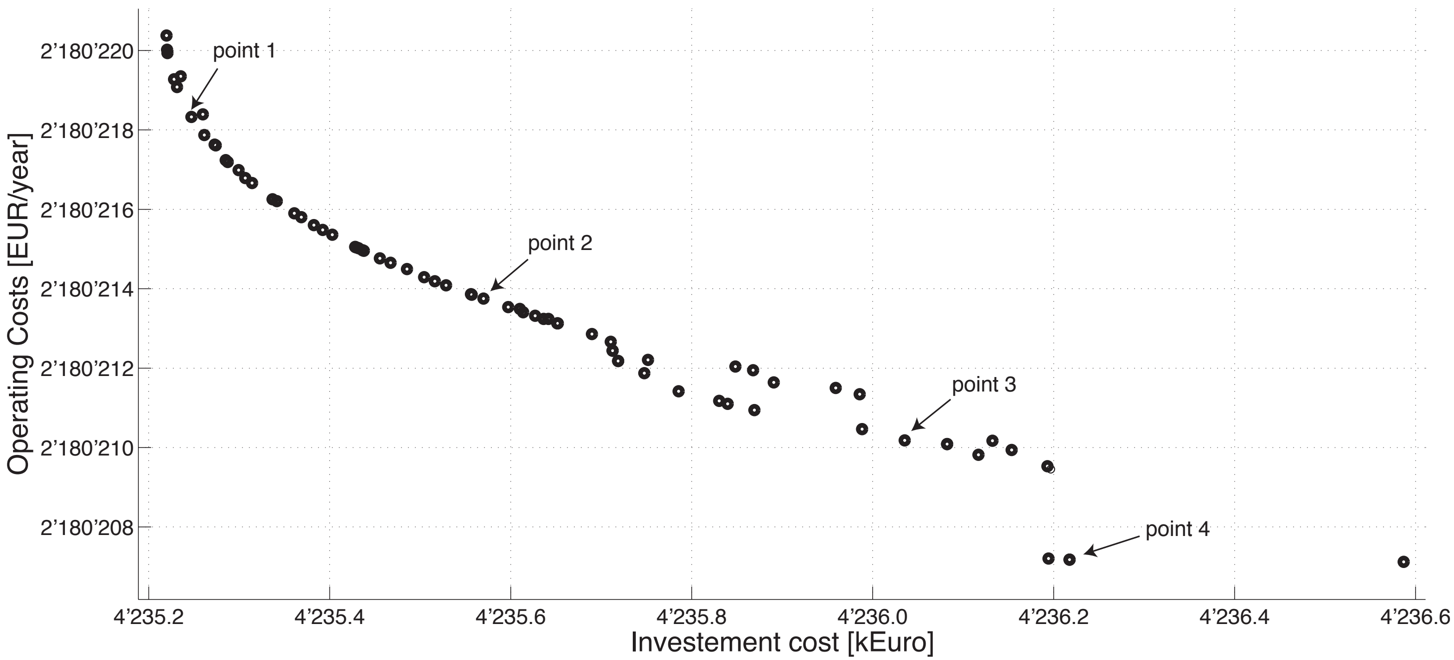
Optimising the heat transfer fluid conditions



$$OpC = F_{obj} = min(c_f^+ \sum_{u=1}^{nu} f_u \dot{E}_{f,u}^+ + c_{el}^+ \sum_{u=1}^{nu} f_u \dot{E}_{el,u}^+ - c_{el}^- \sum_{u=1}^{nu} f_u \dot{E}_{el,u}^-)$$

$$InvC = N_{min} * InvC_{ref} * (A_{mean}/A_{ref})^\gamma$$

Pareto front & Results



Point	OpC [Euro]	InvC [kEuro]	T_{low} [C]	T_{up} [C]
1	2 180 218	4,2353	49.3	69.5
2	2 180 214	4,2356	46.3	73.4
3	2 180 210	4,2361	40.0	78.0
4	2 180 207	4,2362	25.4	81.6
man	2 180 207	4,2363	25.0	80.0

Results

	Unit	No constraints	With constraints	Constraints and heat transfer system
Operating Costs	[kEuro]	2353.6	3844.8	2180.2
Fuel consumption	[kW]	6073	9920	8026
Cooling water	[kW]	1668	5516	1602
Electricity	[kW]			2019

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http://leni.epfl.ch/lenisystem
doi:10.5075/epfl-thesis-5341
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IPESE INDUSTRIAL PROCESS AND

- **Any question ?**