Heat exchanger network design

Pinch design method

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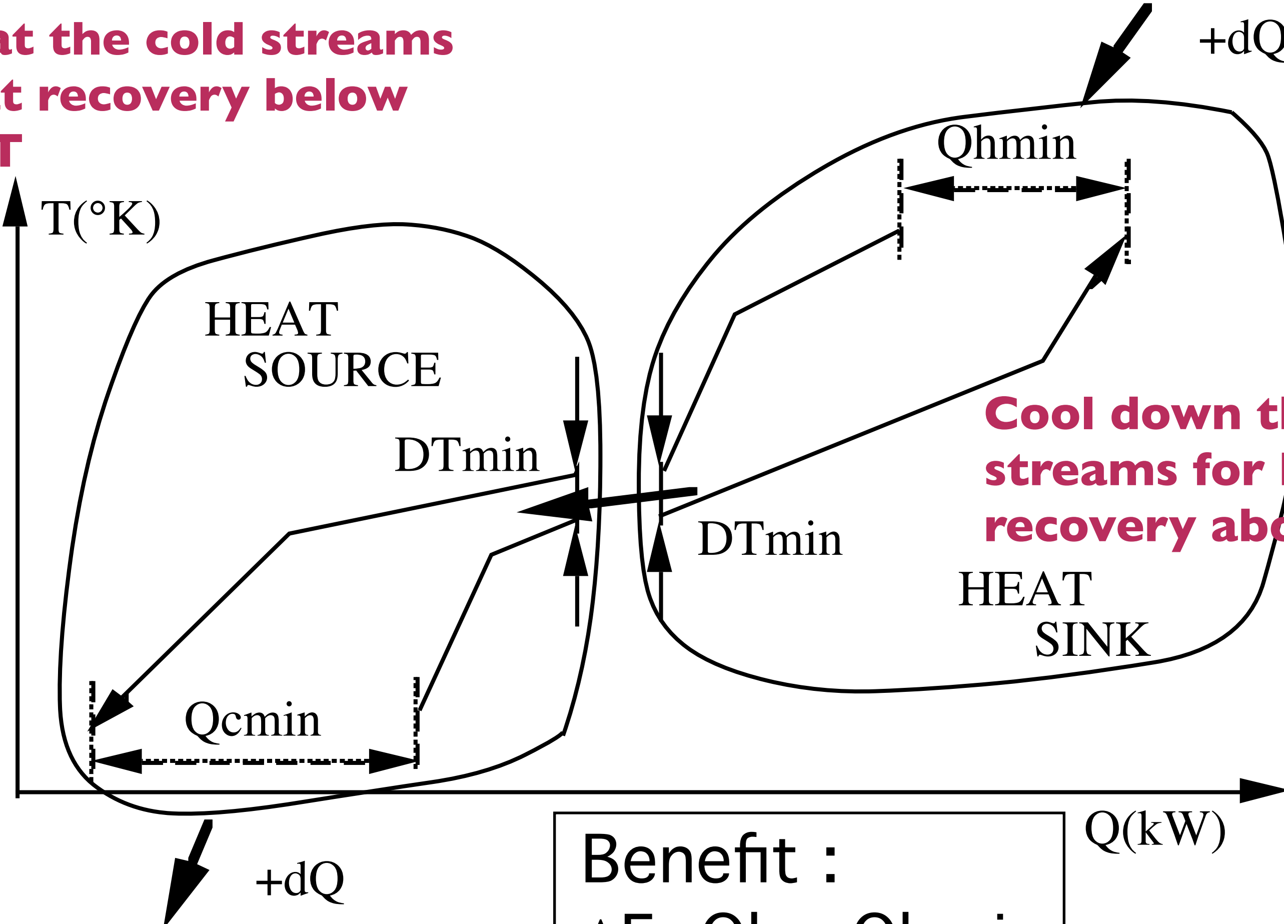
Conclusions of previous steps

- DTmin optimum
- Maximum heat recovery target
  - Utility heat load (hot, cold and refrigeration)
- Pinch point location
- Minimum number of heat exchangers
- Overall DTmin
- Non penalising heat exchangers
  - reduces the list of hot and cold streams to be considered

What is the heat exchanger network ?

The more in - the more out

Preheat the cold streams by heat recovery below pinch T



Benefit :

$\Delta E = Qh - Qhmin$

$\Delta E = Qc - Qcmin$

QH-QC = Constant !

Minimum number of units

Pinch point = two independent sub-systems

Number of Independent sub-systems above the pinch point

Number of Independent sub-systems below the pinch point

$$U_{\min,MER} = (N_{above} - 1 - S_{above}) + (N_{below} - 1 - S_{below})$$

Number of streams above the pinch point

Number of streams below the pinch point

$$U_{\min,MER} = (N_{total} + N_{utility} - 1) + (N_{pinch} - 1) - (S_{above} + S_{below})$$

Number of Independent sub-systems below and above the pinch point

Total number of streams, including the utilities

Number of streams crossing the pinch point

Heat exchangers network synthesis

Find a heat exchangers network that satisfies:
- *MER*
- *Minimum number of units*
- *Minimum investment*
- *Other criteria*

- Which hot stream exchanges with which cold stream ?

- What is the heat exchanged ?

- What is the structure : serial or //, ...

Above pinch point

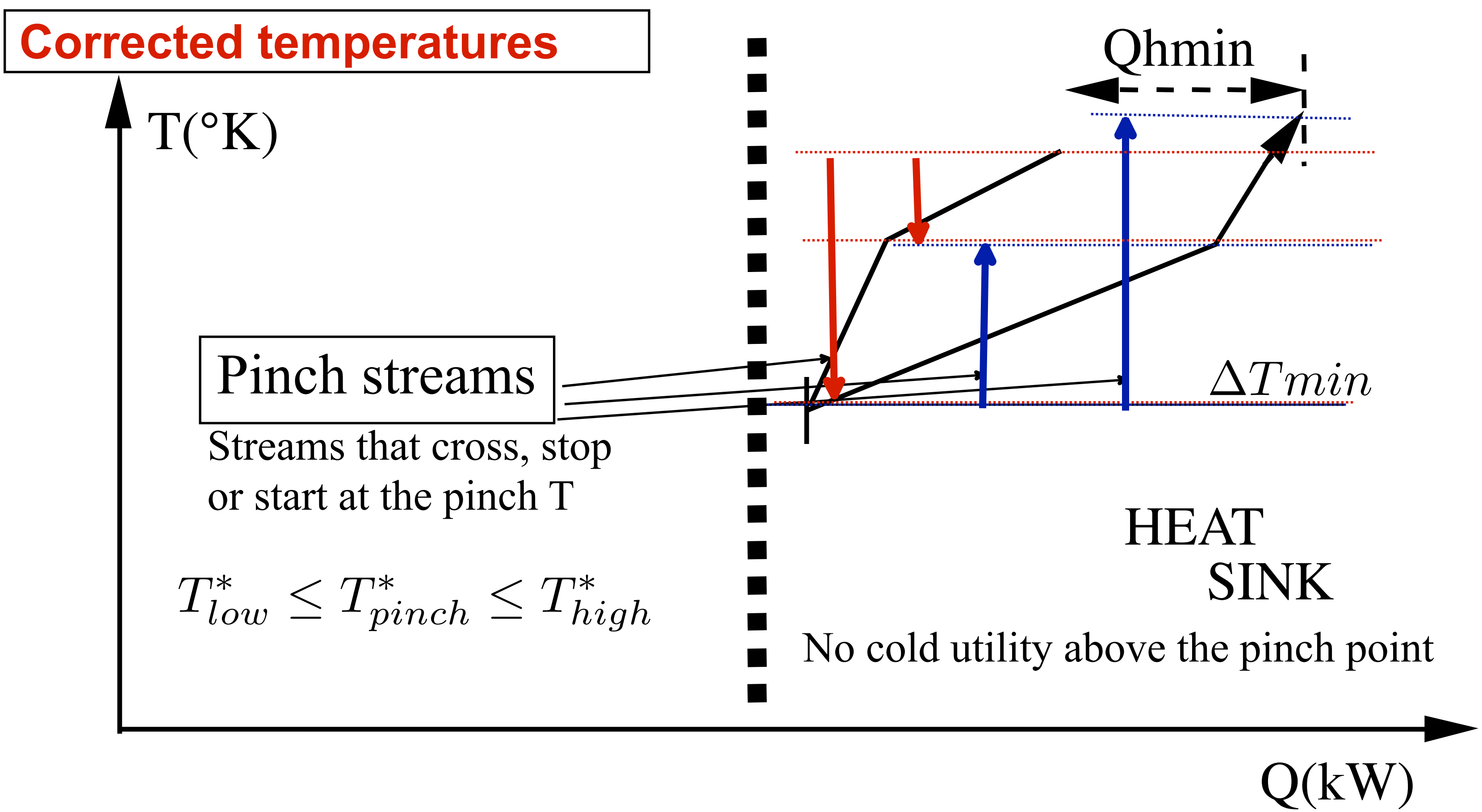
Drive hot streams to the pinch point or target temperature without cold utility

Below pinch point

Drive the cold streams to the pinch point or target temperature without hot utility

Above the Pinch point

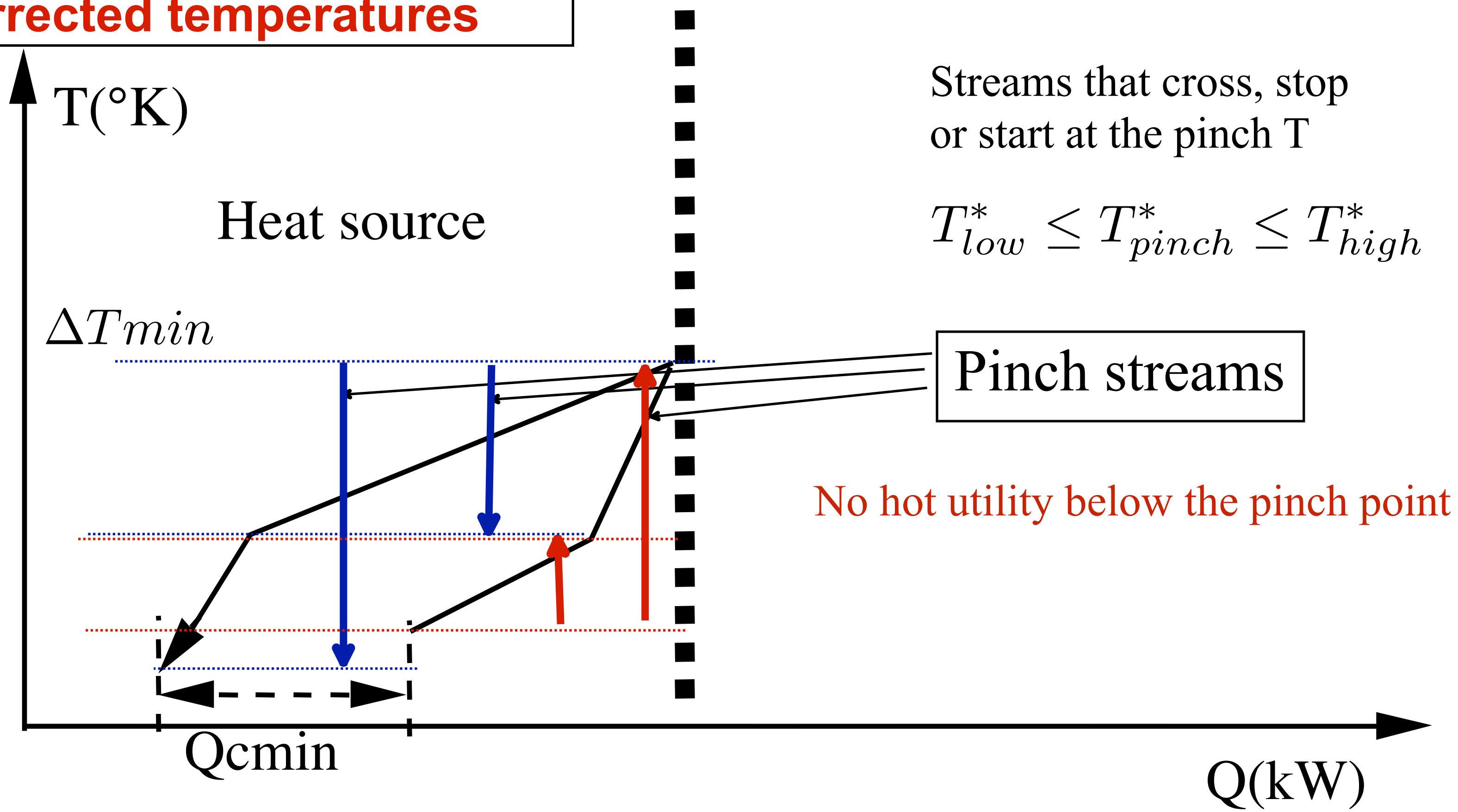
The goal is to cool down hot streams to the pinch temperature or the target temperature without additional utility streams



below the Pinch point

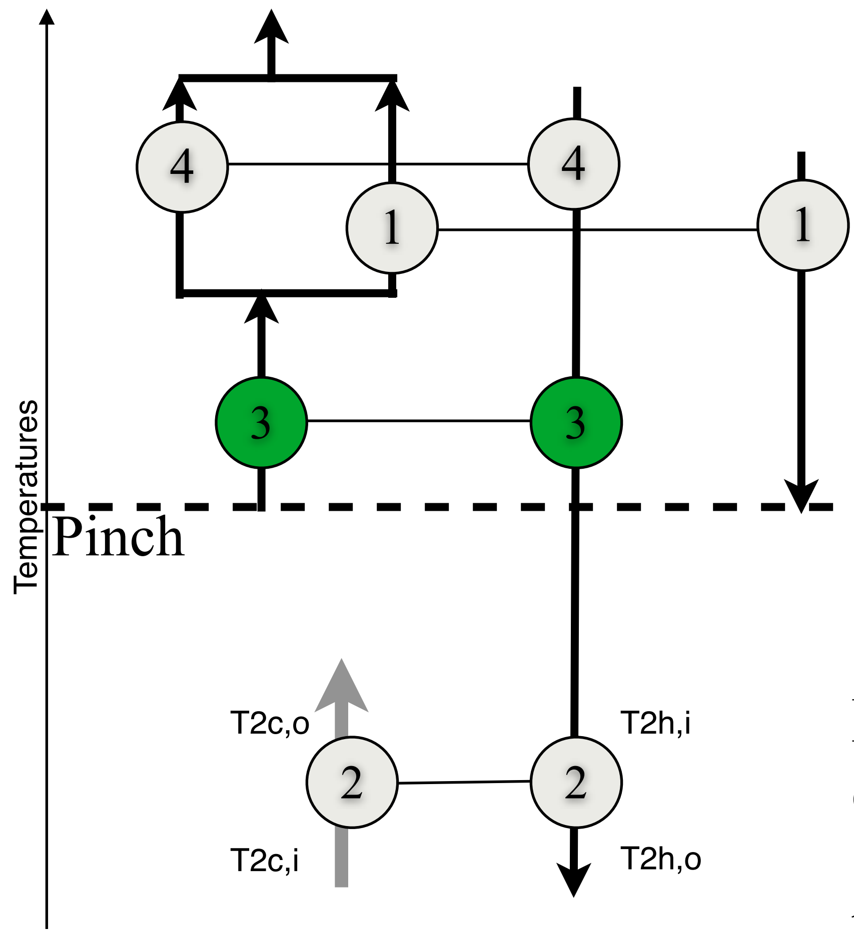
The goal is to heat up cold streams to the pinch temperature or the target without additional hot utility

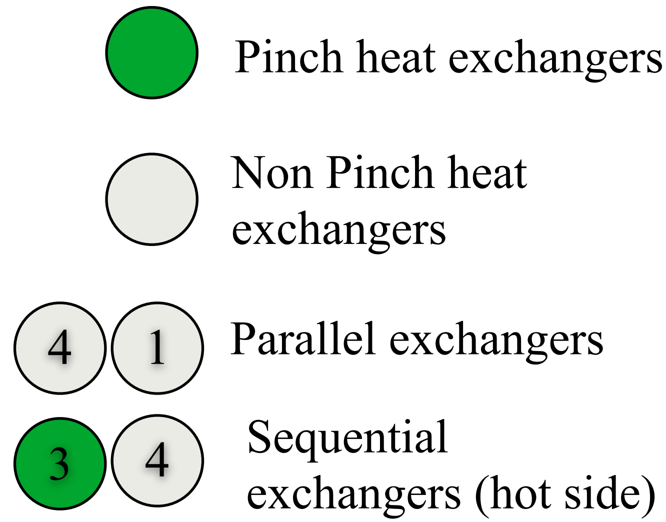
Corrected temperatures



Grid representation of HEN

Streams with inlet and outlet temperatures





Pinch heat exchangers are heat exchanger for which one side (both streams) is at the pinch point, i.e. have $\Delta Tmin$ on one side the counter current heat exchanger

Feasibility rules for heat exchanger placement

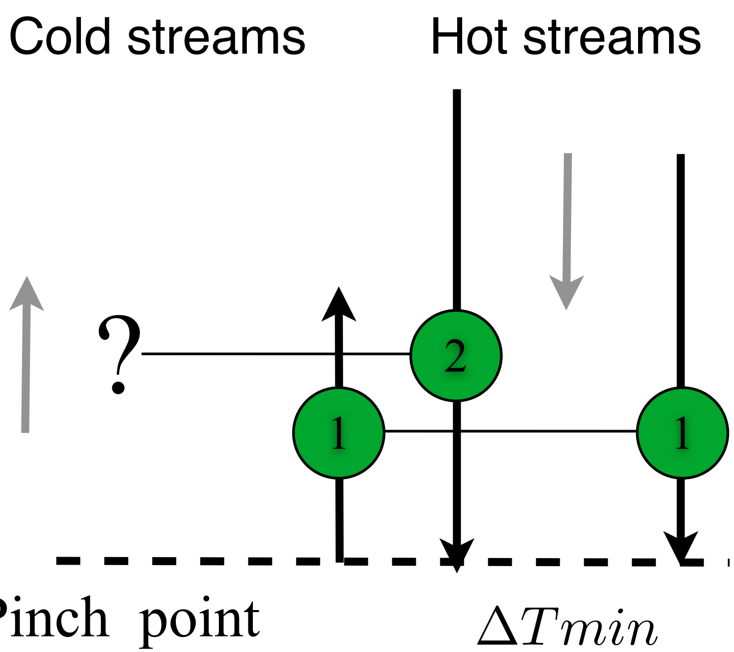
- **For a pinch heat exchanger**
  - Temperature difference on one side is known and is the DTmin
    - in reality $T_h^* - T_c^* = 0$
  - Goal :
    - above : cool down to pinch without cold utility
    - below : heat up to pinch without hot utility
- **=> Feasibility rules for pinch heat exchangers**

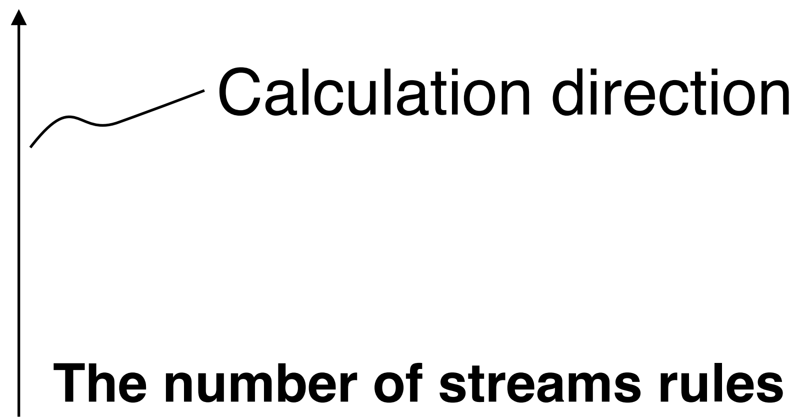
Number of streams rule

Above the pinch :

Start from the pinch point and go towards increasing temperatures

The goal is to cool down hot streams to the pinch without cold utility





$$N_{pinch,c} \geq N_{pinch,h}$$

The number of streams rules

The number of pinch cold streams needs to be higher than the number of pinch hot streams

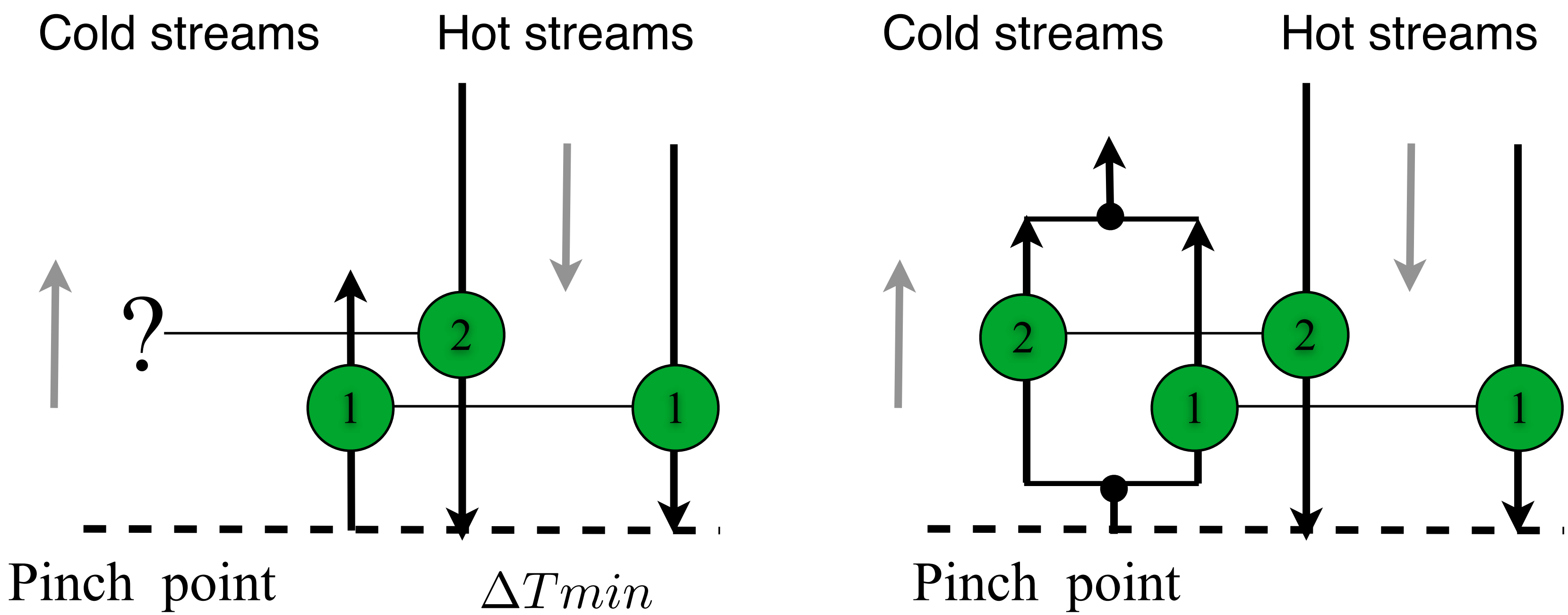
Direction of calculation : from the pinch to the highest temperatures
Note for the key streams (hot streams) we start from the target temperature , i.e. reach the pinch and go to highest temperatures, i.e. to the start temperature. the reverse for the cold streams, we start from the pinch or start temperature and go to the target (finishing with the hot utility).

Number of streams solution : splitting cold streams

Above the pinch :

Start from the pinch point and go towards increasing temperatures

The goal is to cool down hot streams to the pinch without cold utility



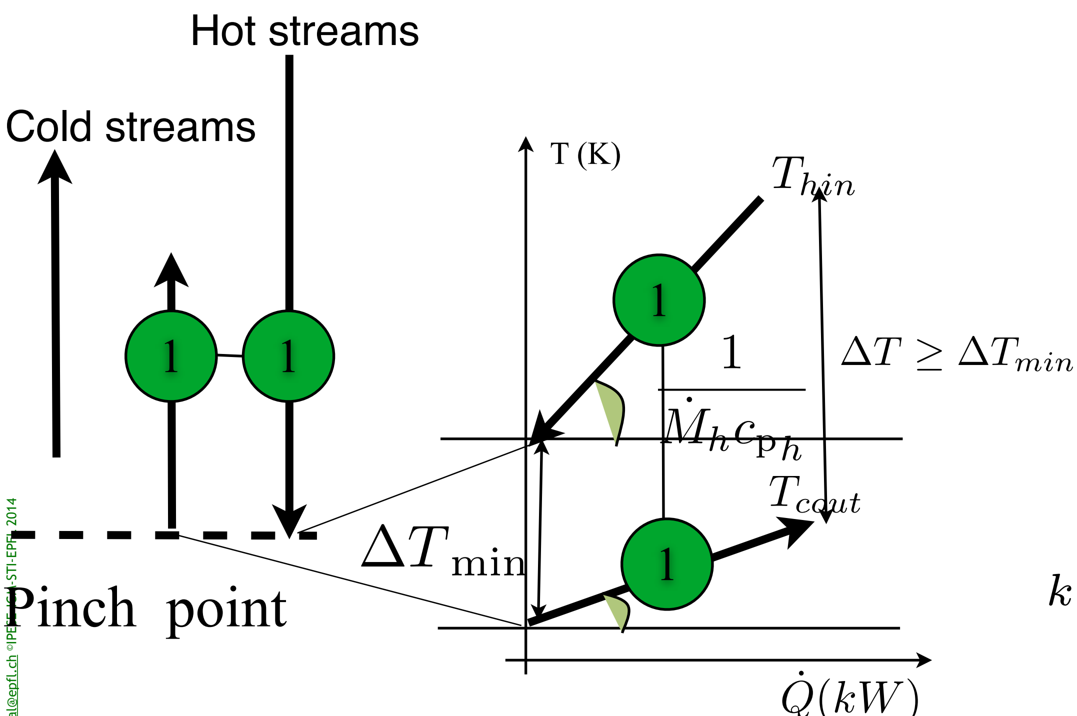
$$N_{pinch,c} \geq N_{pinch,h}$$ otherwise split 1 cold stream

At the pinch we know that the temperature difference is the ΔT_{min} , it can therefore be used as the starting point for the calculation in order to calculate the other side of the counter current heat exchanger

CP Rule : for pinch exchangers above the pinch

Above the pinch :
Start from the pinch point and go towards increasing temperatures
The goal is to cool down hot streams to the pinch without cold utility

Connexion feasibility between c and h



$$\dot{M}c_{p_h} \leq \dot{M}c_{p_c}$$

AND

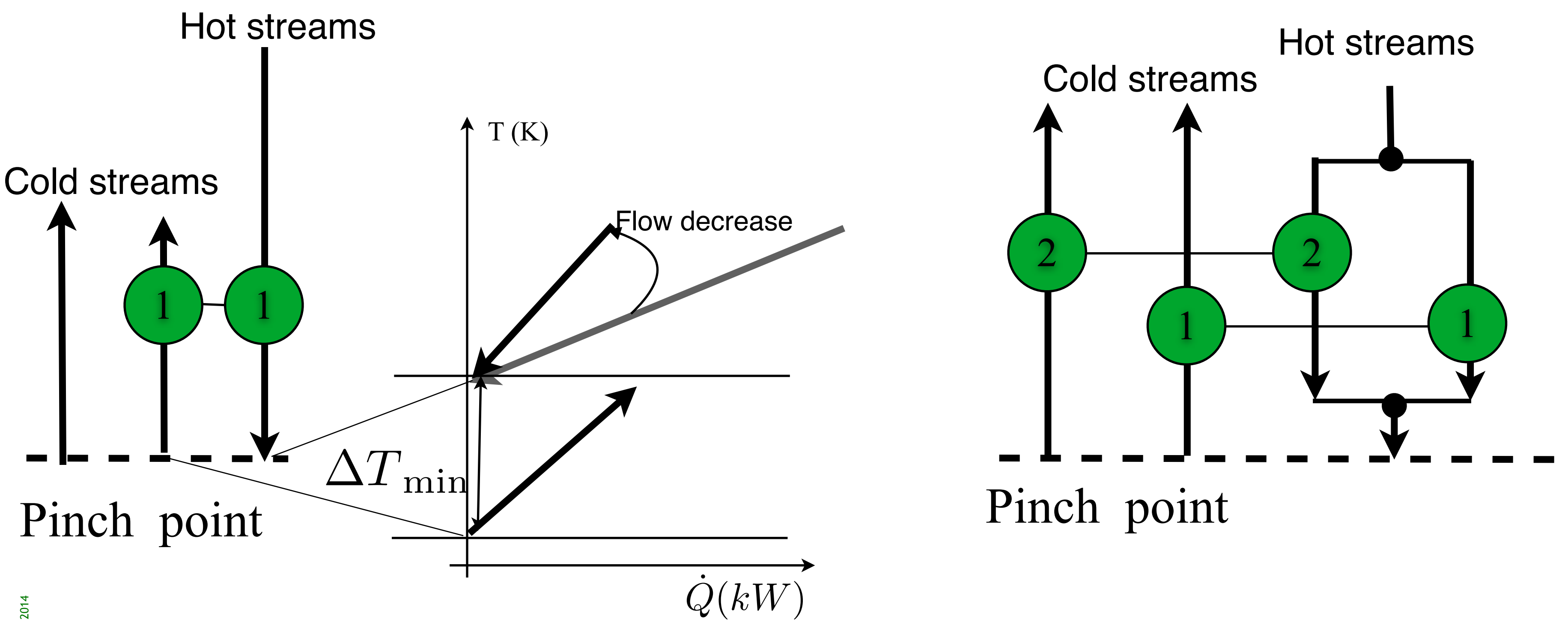
$$\sum_{k=1,k\neq h}^{n_k} \dot{M}c_{p_k} \leq \sum_{j=1,j\neq c}^{n_{k-1}} \dot{M}c_{p_j}$$

At the pinch we know that the temperature difference is the ΔT_{min} , it can therefore be used as the starting point for the calculation in order to calculate the other side of the counter current heat exchanger

EPFL

CP Rule : for pinch exchangers above the pinch

If Cp rule not satisfied split 1 hot stream



This is reducing the Mcp of hot stream in heat exchanger

CP rule is satisfied

Is Number of streams rule still valid ?

Feasibility rules for heat exchanger placement

- **At the pinch point : i.e. for pinch streams**
  - Temperature difference is known : ΔT_{min}
  - Above (or Below) the goal is known
    - above : cool down to pinch without cold utility
    - below : heat up to pinch without hot utility
- **=> Feasibility rules for pinch heat exchangers**
  - Number of streams
  - Cp rule

"this allows to select in the list of streams the one that could be potentially connected"

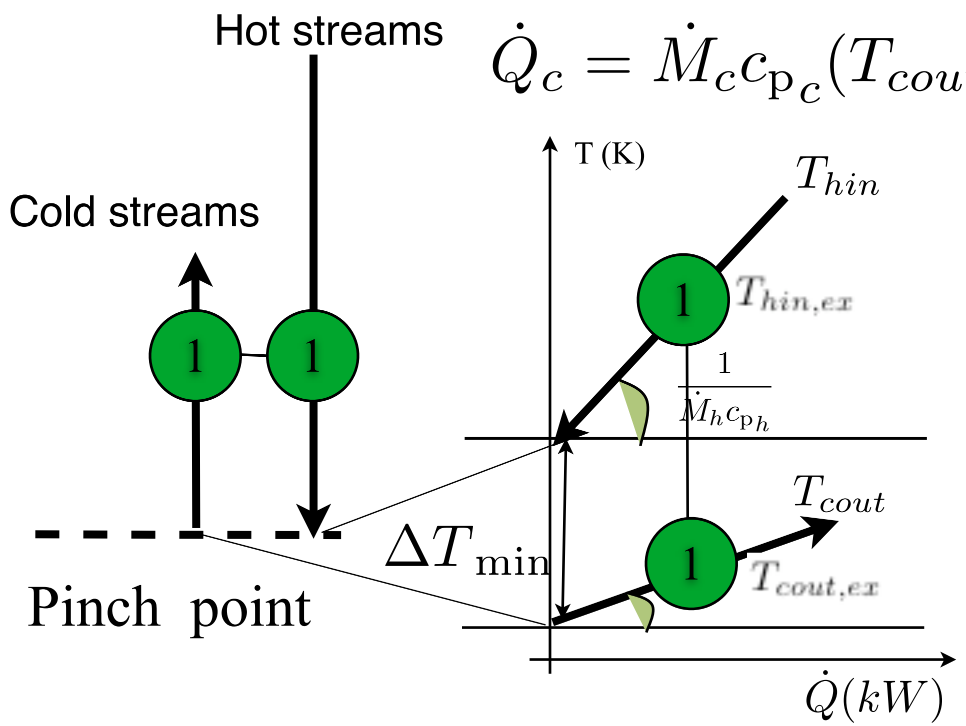
- What is the heat load ?

Tick off rule : satisfy the heat load of one stream

In order to satisfy the minimum number of units rule

$$\dot{Q}_h = \dot{M}_h c_{\mathrm{p}_h}(T_{hin} - (T_p^* + \Delta T_{\min}/2))$$

$$\dot{Q}_c = \dot{M}_c c_{\mathrm{p}_c}(T_{cout} - (T_p^* - \Delta T_{\min}/2))$$



<u>Above the pinch</u>
Calculation starts from the pinch and goes to higher temperatures

Both side !!!

We calculate the inlet conditions of the hot stream and the outlet conditions of the cold stream

$$\dot{Q} = min(\dot{M}_c c_{\mathrm{p}_c}(T_{cout} - (T_p^* - \Delta T_{\min}/2)), \dot{M}_h c_{\mathrm{p}_h}(T_{hin} - (T_p^* + \Delta T_{\min}/2)))$$
$$\Rightarrow T_{hin,ex}, T_{cout,ex}$$

$$T_{hin,ex} = T_p^* + \Delta T_{\min}/2 + \frac{\dot{Q}}{\dot{M}_h c_{\mathrm{p}_h}} \qquad T_{cout,ex} = T_p^* - \Delta T_{\min}/2 + \frac{\dot{Q}}{\dot{M}_c c_{\mathrm{p}_c}}$$

Heuristic rules

1 - Order the streams by decreasing Cp

Goals :

Above the pinch point: cool down the hot streams without cold utilities.

Below the pinch point : heat up the cold streams without hot utilities.

Start with pinch exchangers

2 - verify feasibility rules and split if no connection found

3 - The heat load is calculated to satisfy the heat load of one of the two stream involved : “tick-off”

- work from the pinch

4 - Place the utilities at the end of the streams (control purposes)

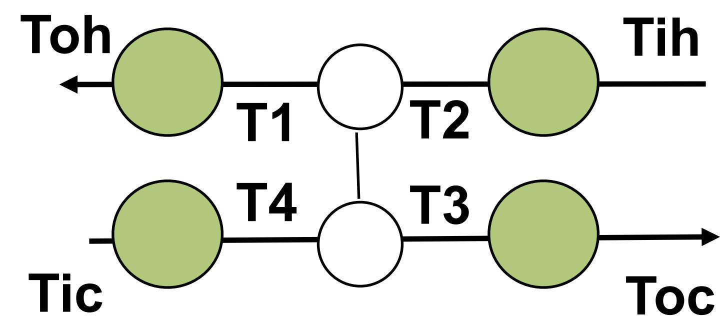
Remaining problem analysis

<u>Initial problem</u>

Hot stream
Tih -> Toh
Cold stream
Tic -> Toc

=> calculate heat cascade => $\dot{Q}^{+^0}$

<u>Place a heat exchanger</u>



<u>Remaining problem</u>

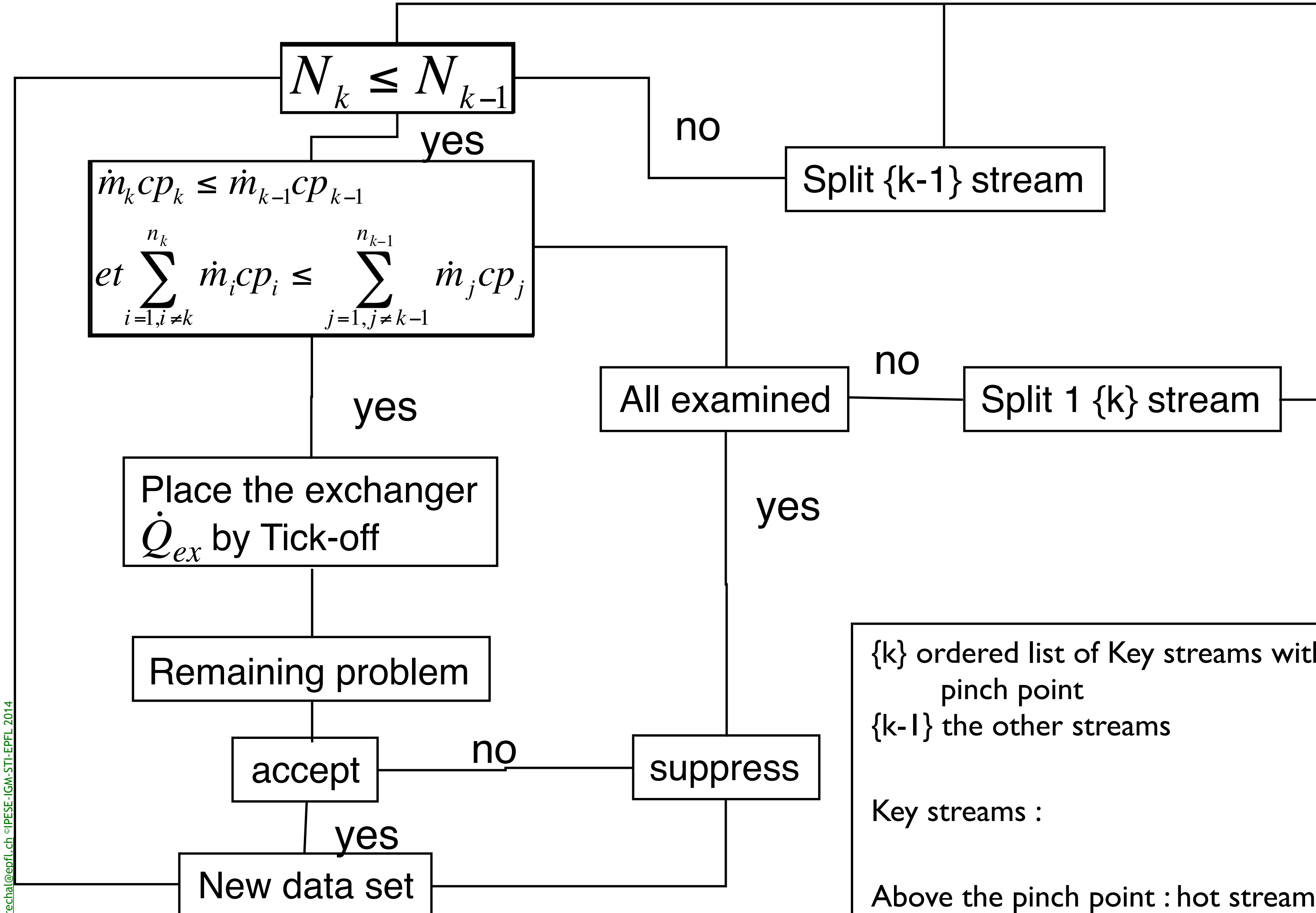
New Hot streams:
Tih -> T2
T1 -> Toh
New Cold streams:
Tic -> T4
T3 -> Toc

=> calcultate heat cascade $\dot{Q}^{+^r}$

if $\dot{Q}^{+^r} = \dot{Q}^{+^0}$
=> Exchanger is well placed

When placing a heat exchanger, the remaining problem analysis consist of calculating the heat recovery with and without the heat exchanger in place (if it is in place the hot and cold streams in the heat exchanger are not anymore considered in the heat cascade). If the minimum energy requirement to close the heat cascade is not changed, the heat exchanger is well placed because it not create an energy penalty in the heat recovery

The synthesis of the HEN synthesis algorithm



{k} ordered list of Key streams with decreasing Cp at the pinch point
{k-1} the other streams

Key streams :

Above the pinch point : hot streams
Below the pinch point : cold streams