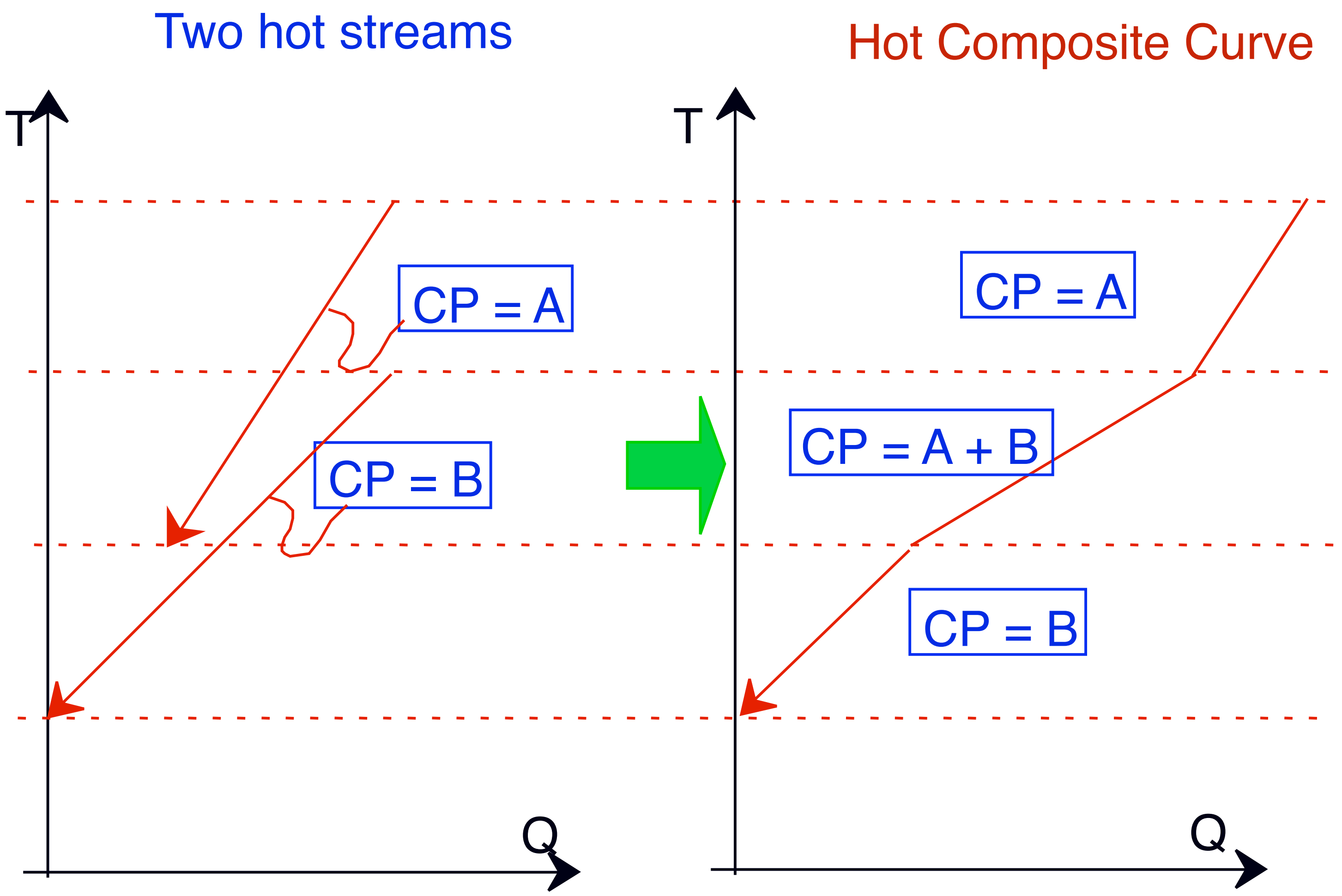
Process integration

Targeting the maximum heat recovery in a process

Prof François Maréchal
IPESE-IGM-EPFL
Industrial Process and Energy Systems Engineering

Composite curves

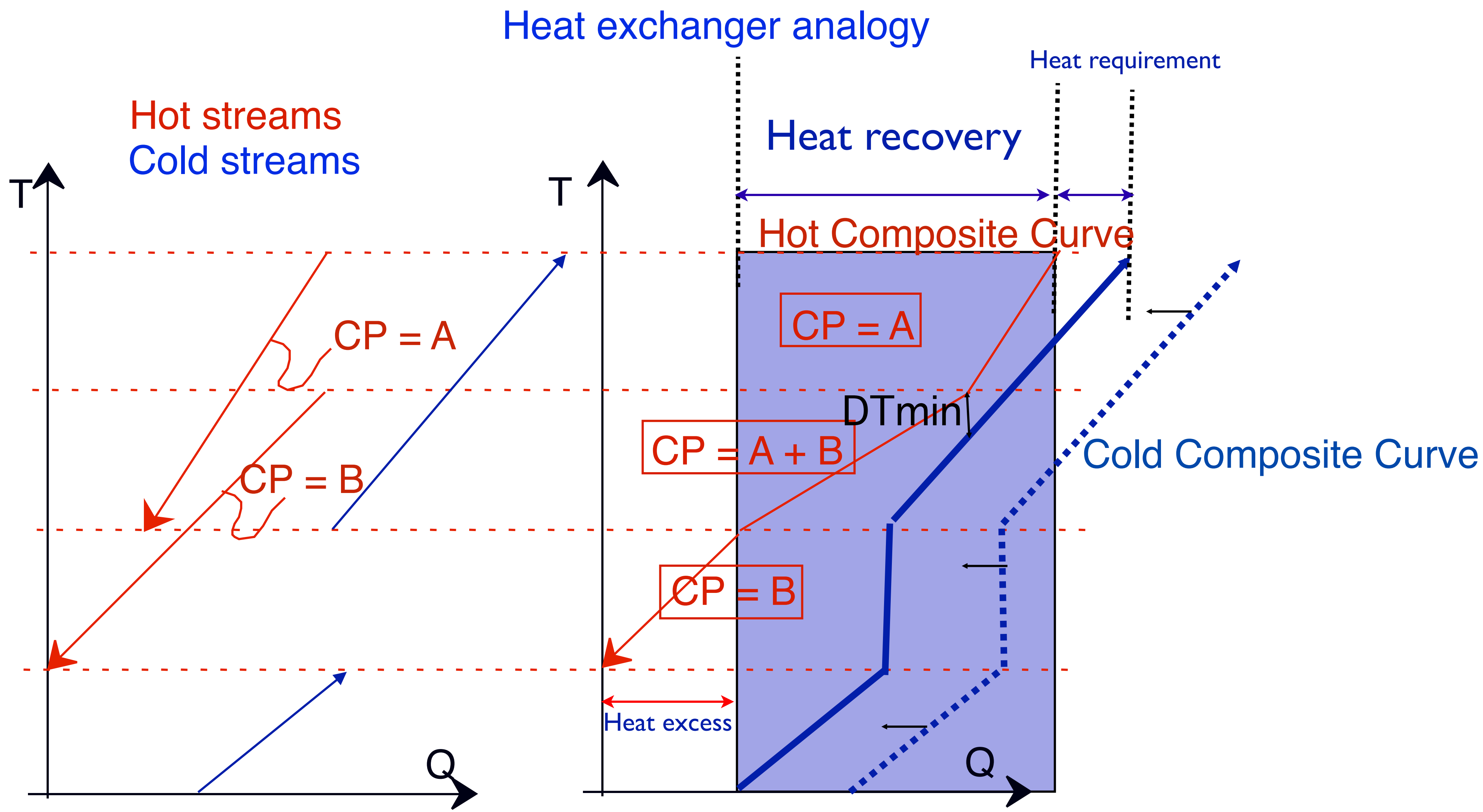
The heat-temperature profile of the heat available in the hot streams as a function of the temperature



This is the integral of the heat made available for the heat exchange in the system. This is like if there would be a centrale heat exchange system t would receive all the hot streams in a single heat exchanger therefore creating a non constant heat temperature profile.

Composite curves and pinch point

EPFL

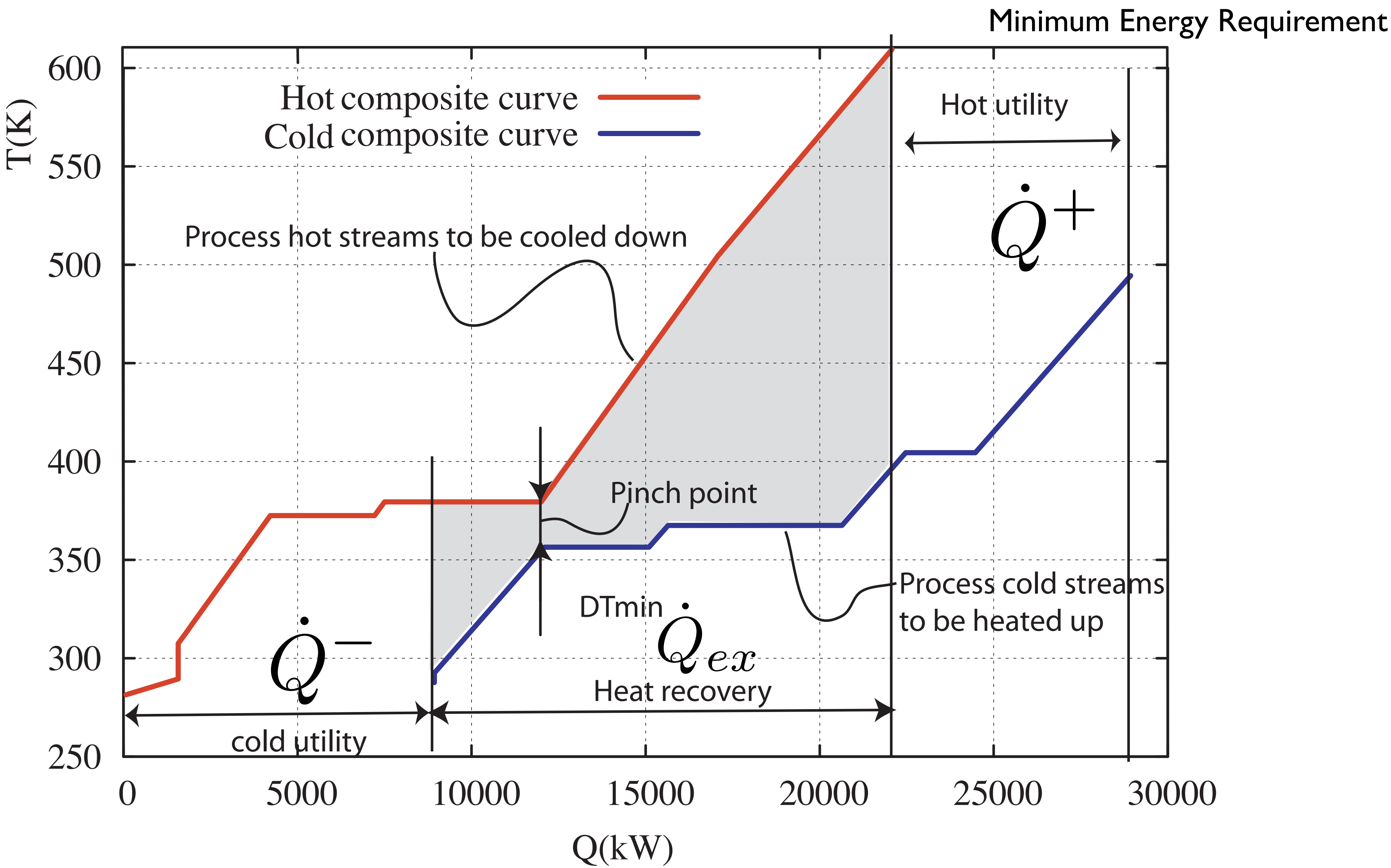


Heat excess and Heat by energy balance from the hot and cold streams needs

We consider that the global cold stream (cold composite) can receive heat from the cold global hot stream (hot composite), provided that the temperature of the hot stream is higher enough than the temperature of the cold streams. The theory of the counter current heat recovery between two streams is valid and allows to maximise the heat recovery between the hot and the cold streams in the system, independently of the system size and of the number of streams considered.

Hot and cold composite curves

EPFL



When the pinch point is activated, we can identify the heat recovery between hot and cold streams. By balance the heat supplied from outside (named hot utility) is the heat needed by the cold streams minus the heat recovery. For the hot streams the heat to be released outside the system (named the cold utility) is the total heat available in the hot streams from which we deduce the heat recovery.

Minimum Energy Requirement results

- Heat Balances

$$\text{Heat from the hot streams : } \dot{Q}^{+}_{hot} = \sum_{i=1}^{n_{hot}} \dot{Q}^{+}_{i}$$

$$\text{Heat to the cold streams : } \dot{Q}^{-}_{cold} = \sum_{j=1}^{n_{cold}} \dot{Q}^{-}_{j}$$

- Pinch point constraint
  - DTmin Value
- Results

Minimum heat requirement as hot utility: $\dot{Q}^{+}$

Maximum heat recovery in heat exchangers :

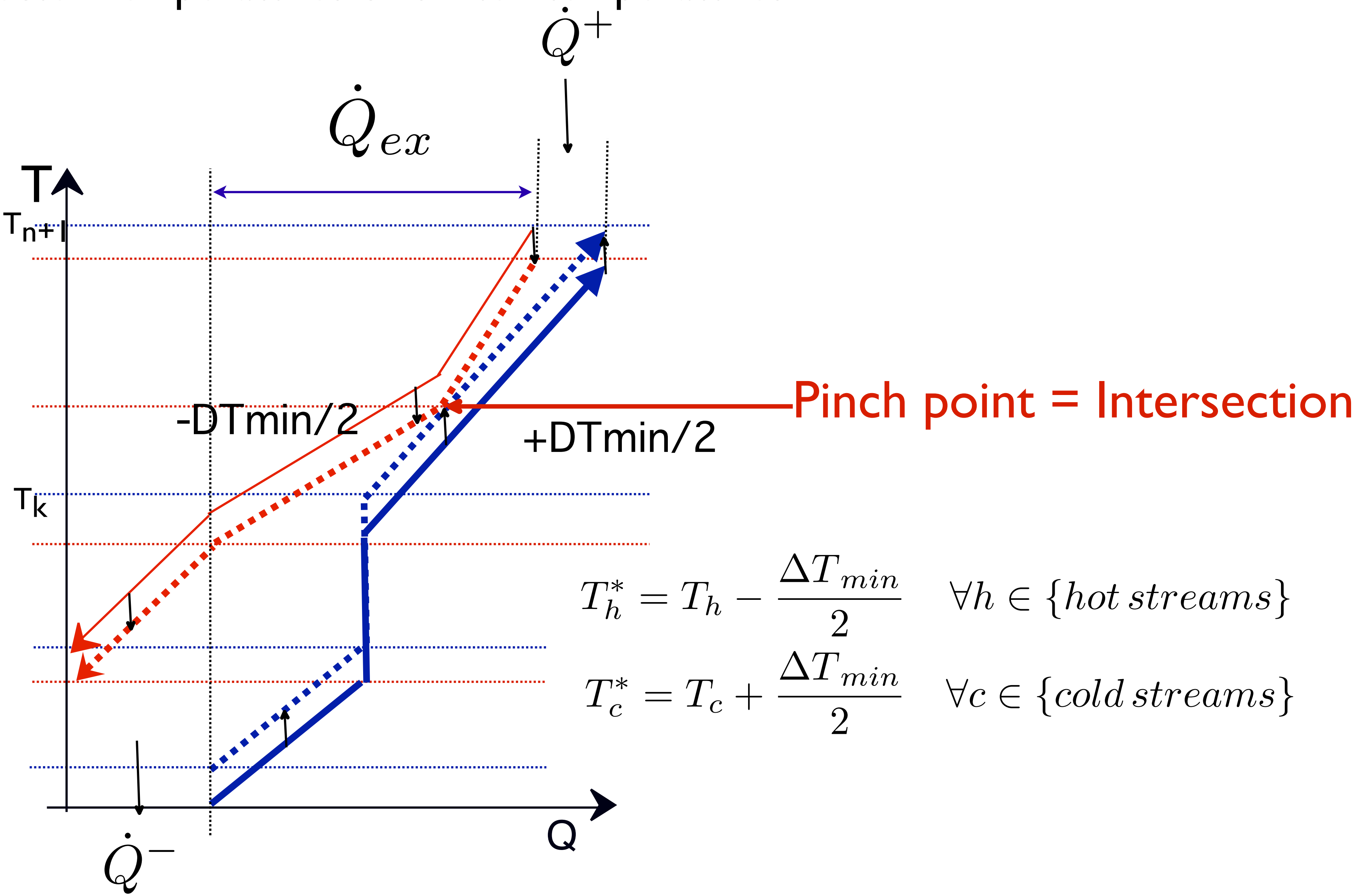
$$\dot{Q}_{ex} = \dot{Q}^{-}_{cold} - \dot{Q}^{+} = \dot{Q}^{+}_{hot} - \dot{Q}^{-}$$

Minimum cooling requirement as cold utility:

$$\dot{Q}^{-} = \dot{Q}^{+} + \dot{Q}^{+}_{hot} - \dot{Q}^{-}_{cold}$$

Calculation of the minimum energy requirement

Corrected Temperatures or shifted temperatures



$$T_h^* = T_h - \frac{\Delta T_{min}}{2} \quad \forall h \in \{hot\ streams\}$$

$$T_c^* = T_c + \frac{\Delta T_{min}}{2} \quad \forall c \in \{cold\ streams\}$$

An intersection of two curves can be easier to calculate than a vertical distance between two curves. In the corrected or shifted temperature domain (this is a change in the scale), the two curves are intersecting. In the corrected temperature domain, when a hot stream has a corrected temperature higher than the corrected temperature of a cold stream, it can exchange his heat in an economically acceptable way (as calculated with the DTmin assumption).

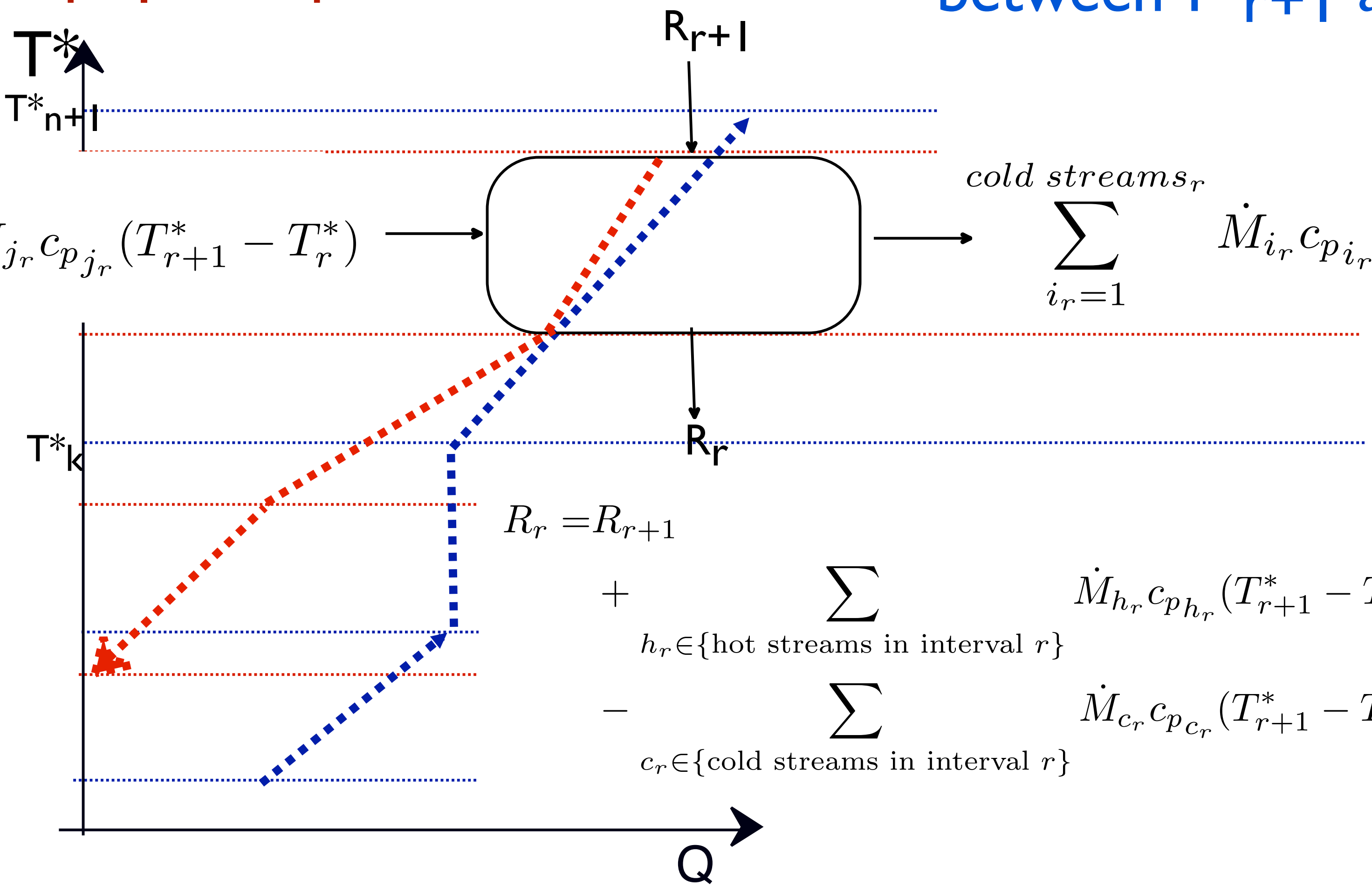
Heat balance in one corrected temperature interval

Change in the scale : Corrected temperatures !

Heat from the hot streams between T^*_{r+1} et T^*_r

Heat to the cold streams between T^*_{r+1} and T^*_r

$$\sum_{j_r=1}^{hot\ streams_r} \dot{M}_{j_r} c_{p_{j_r}} (T^*_{r+1} - T^*_r) \rightarrow \quad \rightarrow \sum_{i_r=1}^{cold\ streams_r} \dot{M}_{i_r} c_{p_{i_r}} (T^*_{r+1} - T^*_r)$$



$$R_r = R_{r+1} + \sum_{h_r \in \{\text{hot streams in interval } r\}} \dot{M}_{h_r} c_{p_{h_r}} (T^*_{r+1} - T^*_r) - \sum_{c_r \in \{\text{cold streams in interval } r\}} \dot{M}_{c_r} c_{p_{c_r}} (T^*_{r+1} - T^*_r) \quad \forall r = 1, ..., n_r$$

Heat cascade : [R_r, T^*_r] , $R_r \geq 0$

The flow from higher temperatures to lower temperatures in the corrected temperature domain is defined as being the heat cascade. It is the amount of heat that flows from higher temperatures to lower temperatures. This flow needs to be greater than zero.

Heat cascade

EPFL

$$\min_{R_r} \dot{Q}^+ = R_{n_r+1}$$

subject to heat balance of the temperature intervals :

$$\begin{aligned} R_r = & R_{r+1} \\ & + \sum_{h_r \in \{\text{hot streams in interval } r\}} \dot{M}_{h_r} {c_p}_{h_r} (T^*_{r+1} - T^*_r) \\ & - \sum_{c_r \in \{\text{cold streams in interval } r\}} \dot{M}_{c_r} {c_p}_{c_r} (T^*_{r+1} - T^*_r) \end{aligned} \quad \forall r = 1, ..., n_r$$

and the heat cascade feasibility

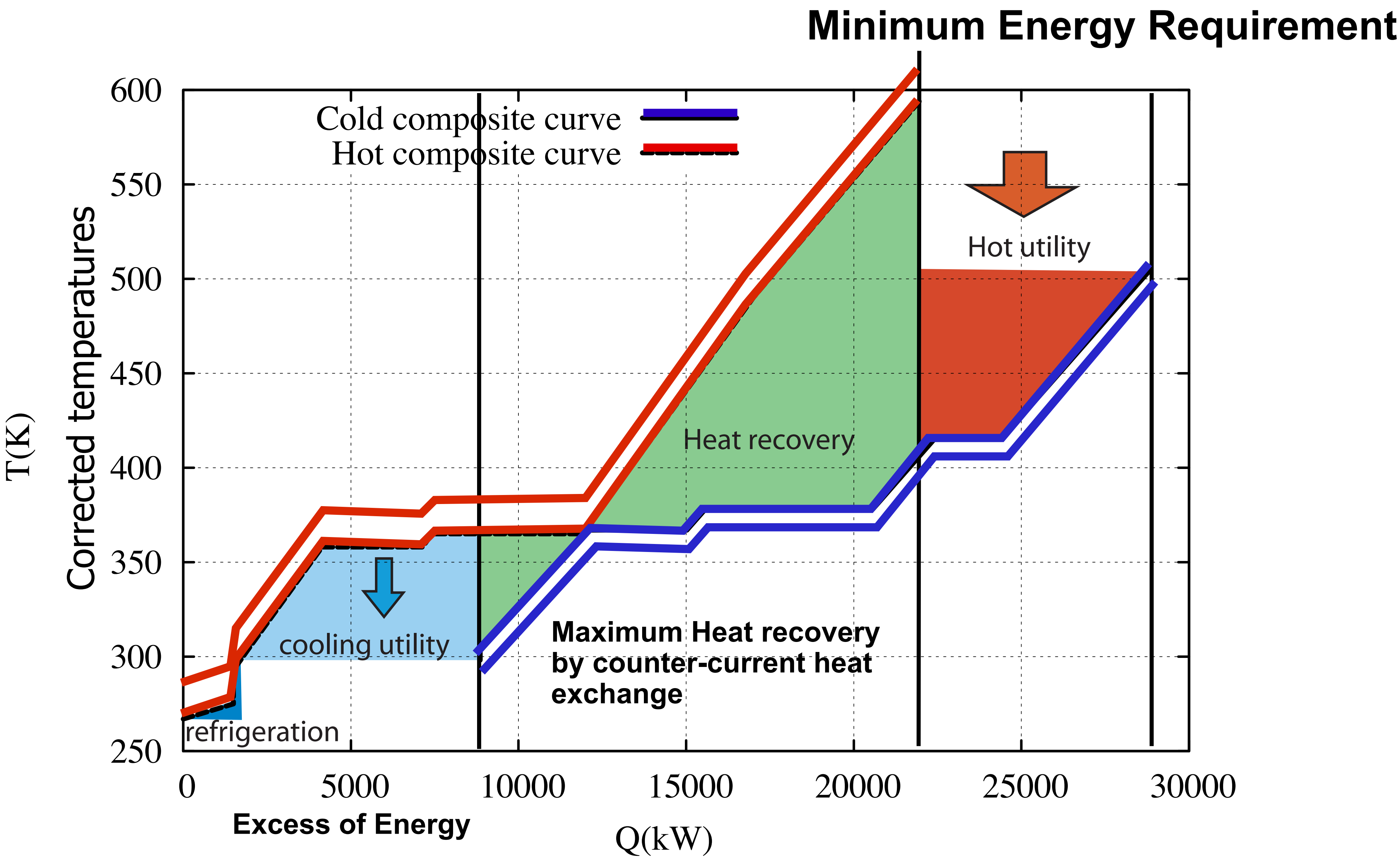
$$R_r \geq 0 \quad \forall r = 1, ..., n_r + 1$$

$$T^*_h = T_h - \frac{\Delta T_{min}}{2} \quad \forall h \in \{hot\, streams\}$$

$$T^*_c = T_c + \frac{\Delta T_{min}}{2} \quad \forall c \in \{cold\, streams\}$$

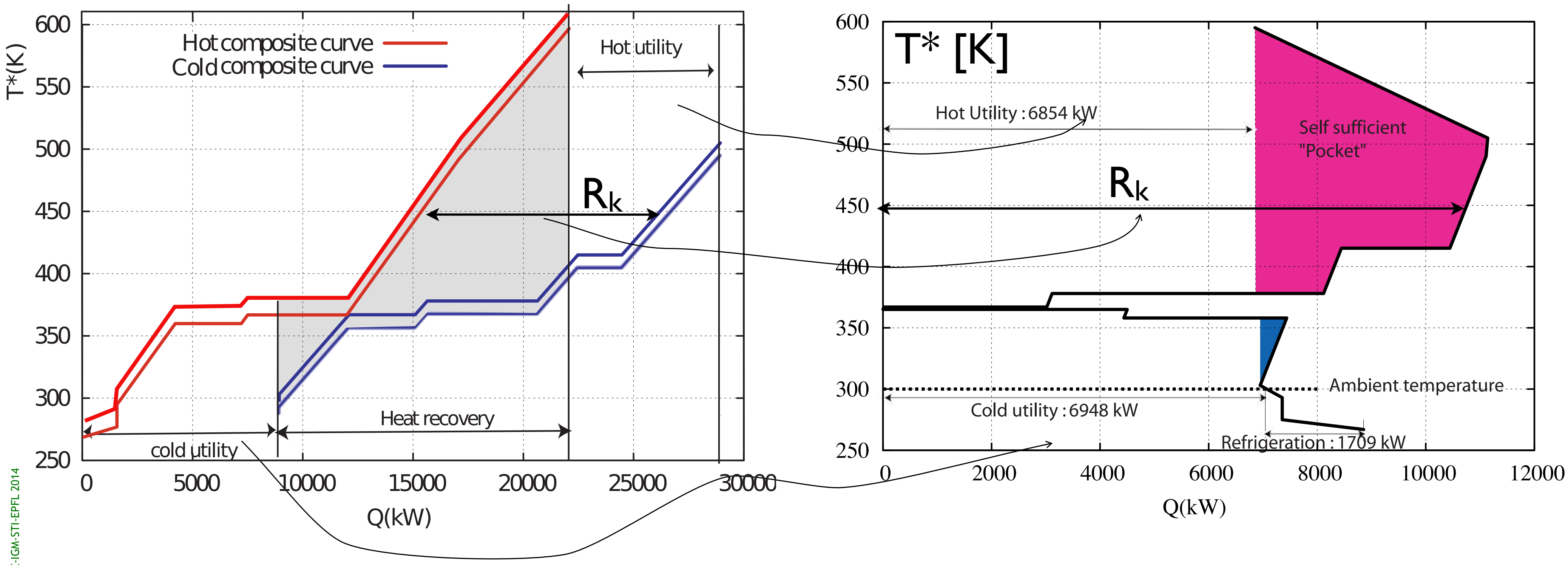
The fact that we look for the minimum of heat input is going to tell us that one of the inequality contraints (Rr≥0) will be activated.The place where the constraint is activated is defined as being the pinch point.

Maximum heat recovery Target



Grand composite curve/Heat cascade

- Corrected temperature domain
- Graphical plot of the heat cascade : [R_r, T^*_r] r=1,n_r



The Grand composite is the heat cascade representation in the corrected temperature domain. it represents the flow of energy in the system from higher temperatures to lower temperature. Above the pinch point is also represents the heat-temperature profile of the heat to be supplied to the system and below the pinch it represents the heat-temperature profile of the heat available in the process and to be removed from the system.

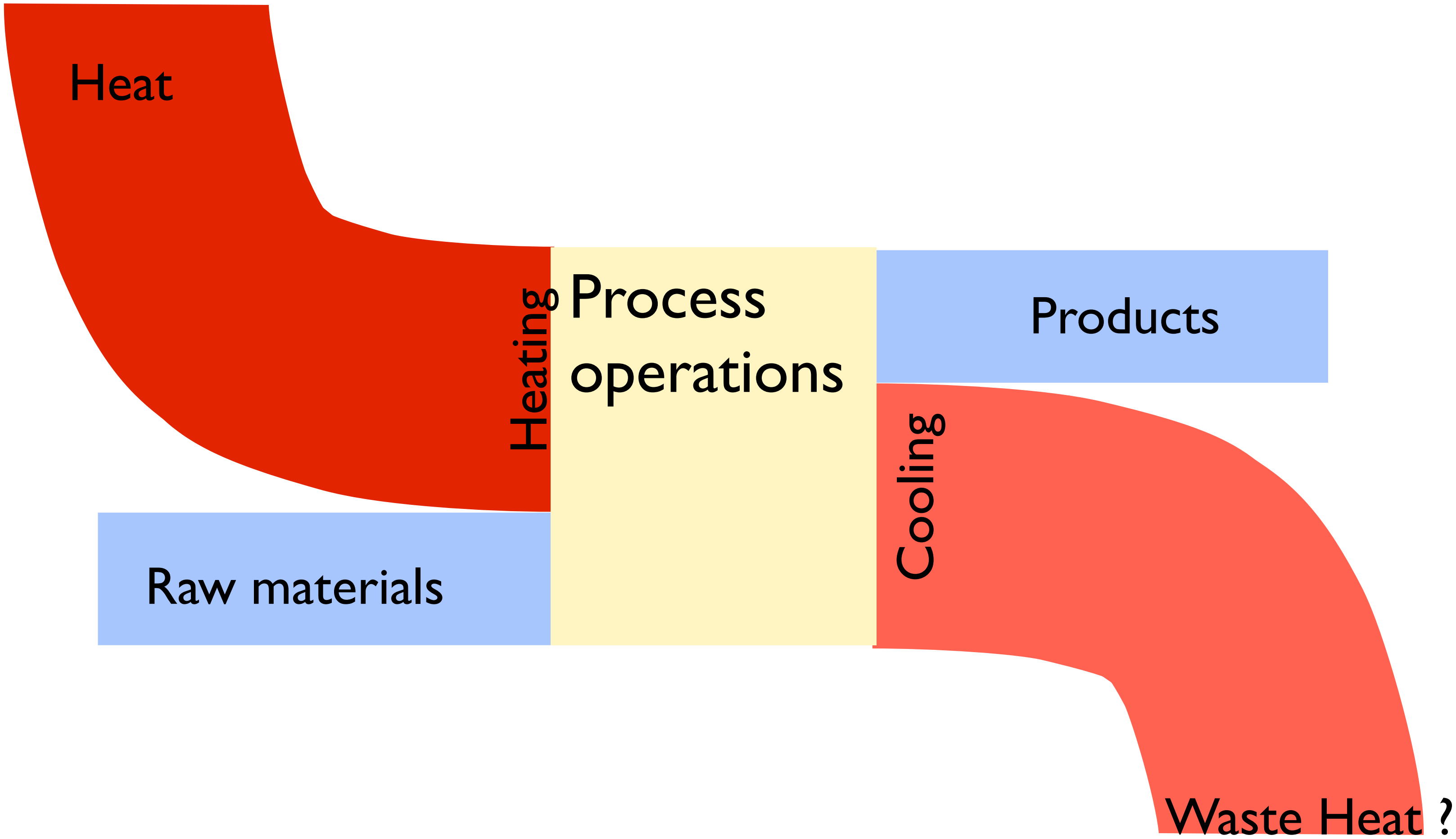
Conclusions

- **Hot and cold streams for the overall system**
  - Composite curves
- **From the DTmin assumptions**
  - Maximum heat recovery
  - Minimum hot&cold utility
  - Energy savings
- **Algorithm for calculating maximum heat recovery**
  - Problem table
  - Corrected temperature
  - Heat cascade => Grand composite curve

- The More-in The More-out

The more In / The more Out

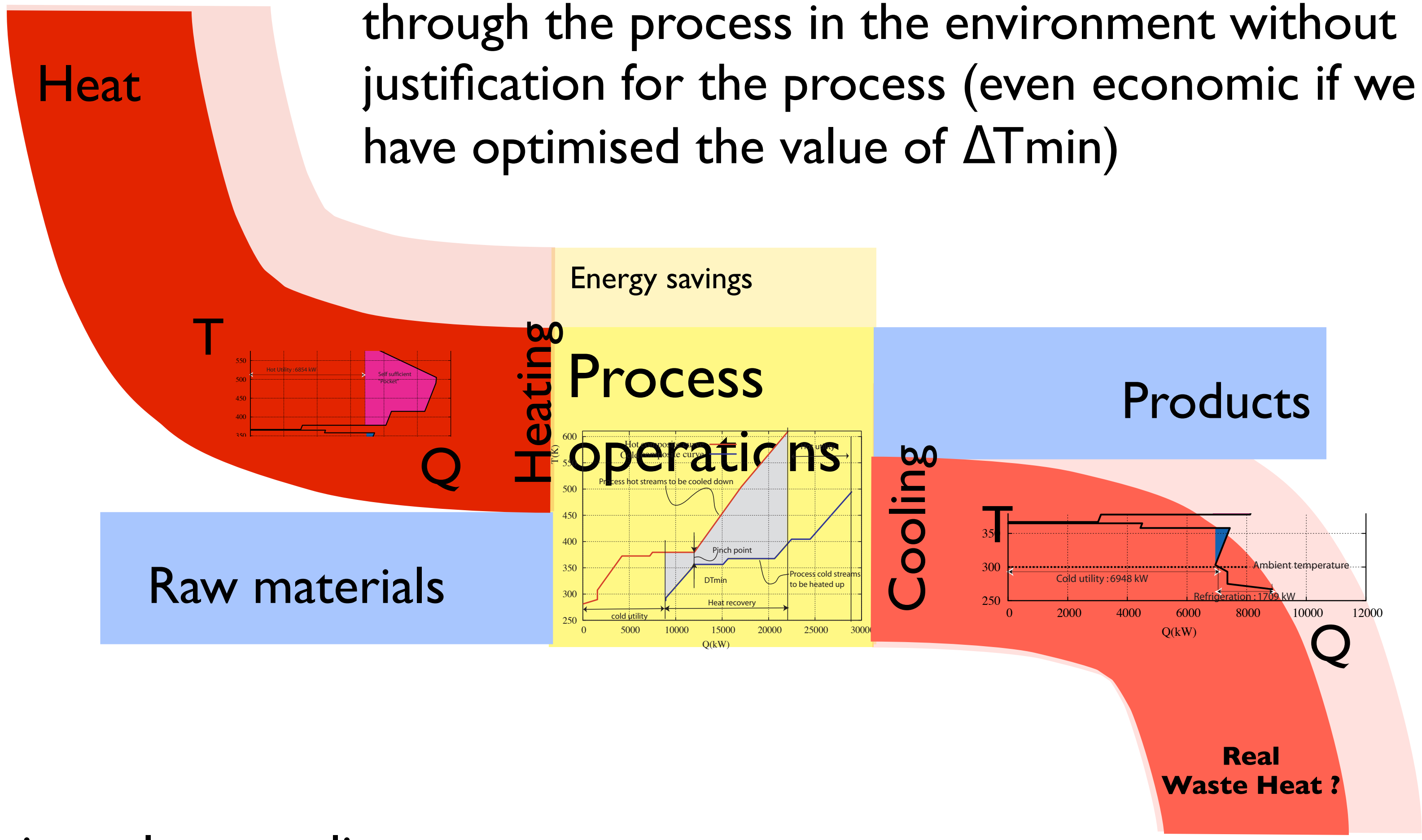
EPFL



By energy balance, the energy entering the system is leaving the system, if it does not leave in the product it has to leave as the cold utility

Energy Usage : The more in / The More Out

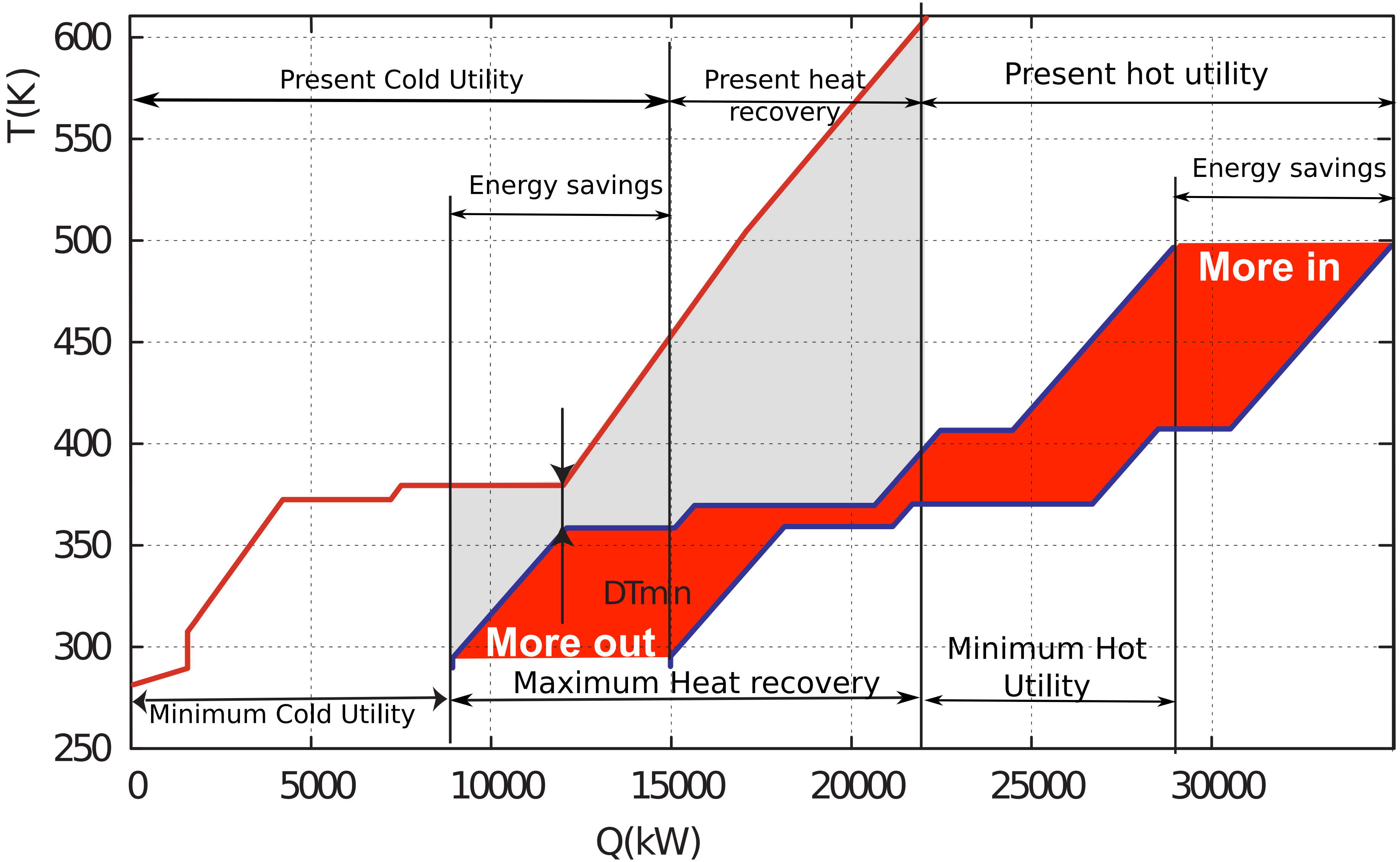
The energy saving is the amount of heat that flows through the process in the environment without justification for the process (even economic if we have optimised the value of ΔTmin)



Less Heating = Less cooling

By energy balance, the reduction in the heat requirement corresponds to a reduction of the heat released by the process and to be evacuated by a cold utility. Heat recovery leads therefore to savings in the hot utility and by energy balance to the reduction of the waste heat of the process that is released to the environment by the hot utility.

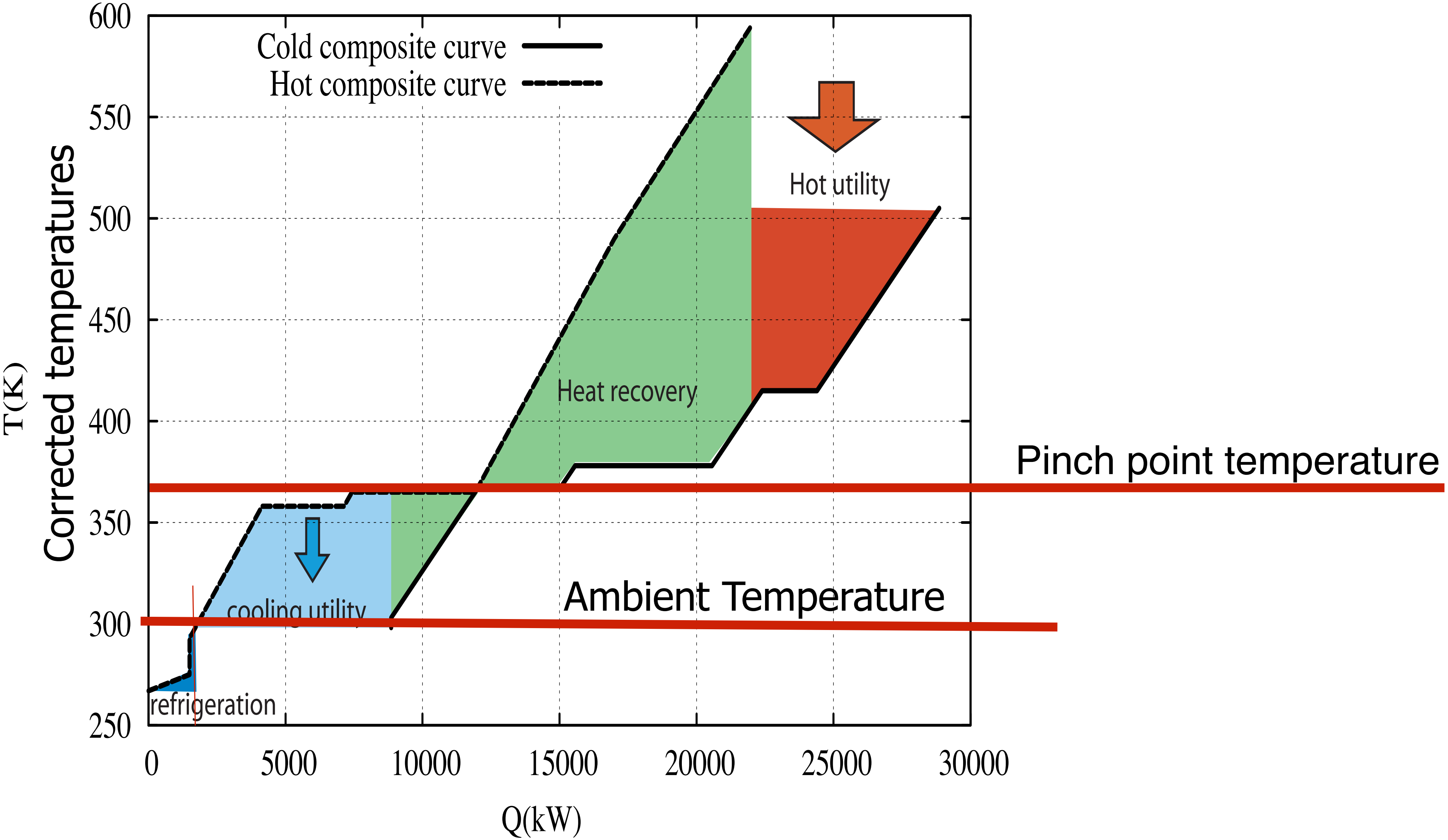
The More-in More-out Principle



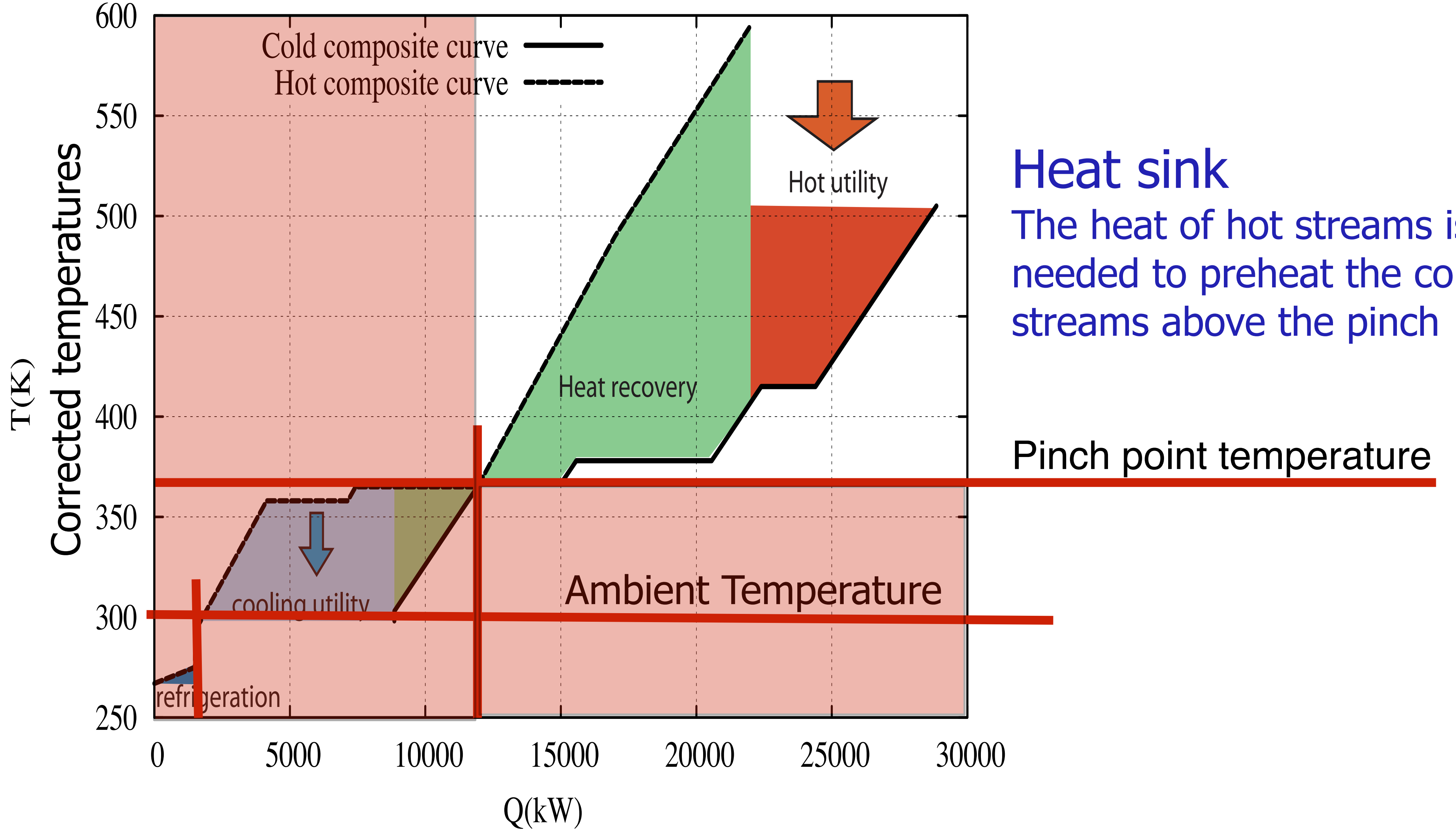
Saving of hot utility = Saving of cold utility

Savings of hot utility = Amount of heat that you buy today to heat the environment

3 Independent sub-systems



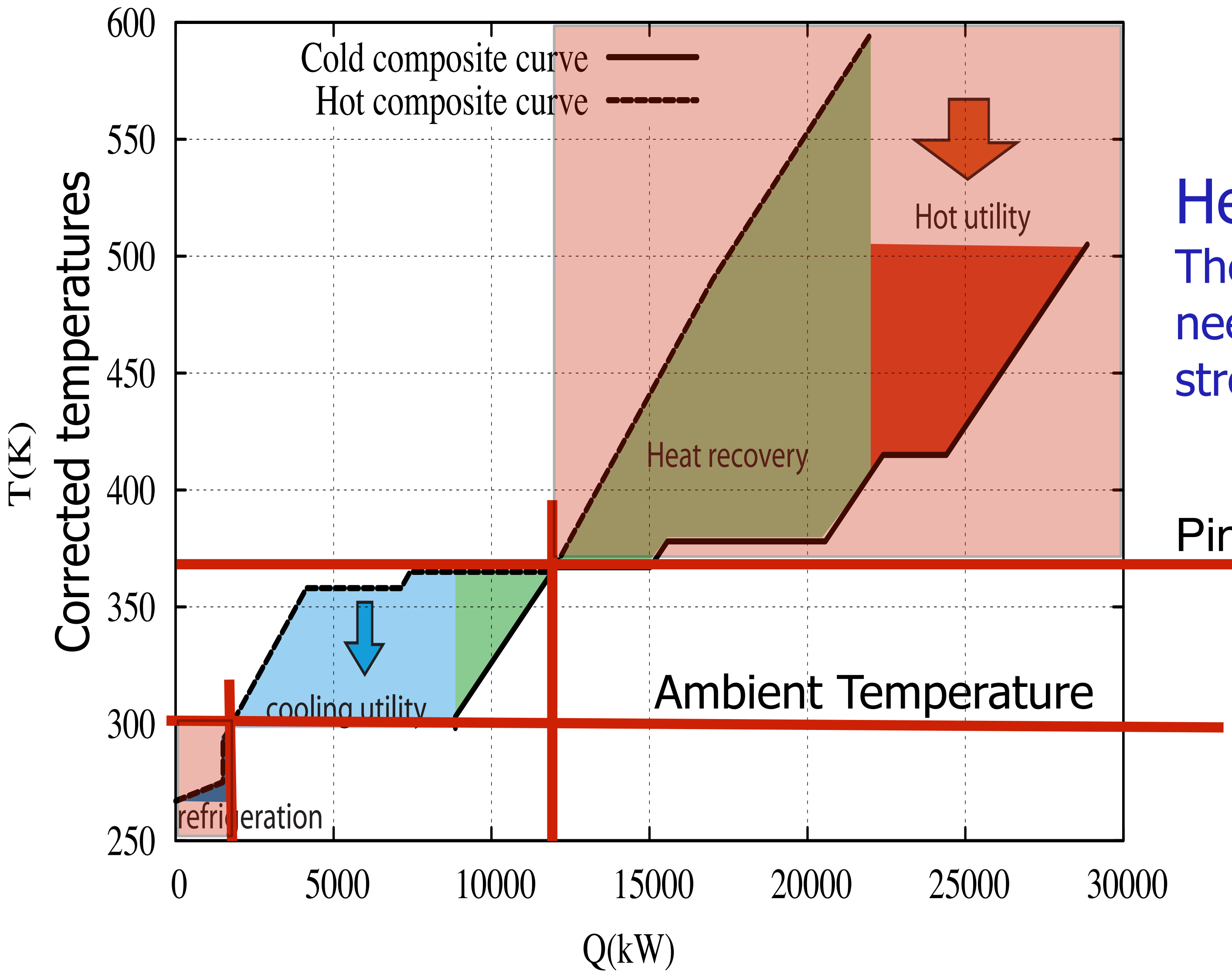
3 Independent sub-systems



Heat sink

The heat of hot streams is needed to preheat the cold streams above the pinch

3 Independent sub-systems



Heat sink

The heat of hot streams is needed to preheat the cold streams above the pinch

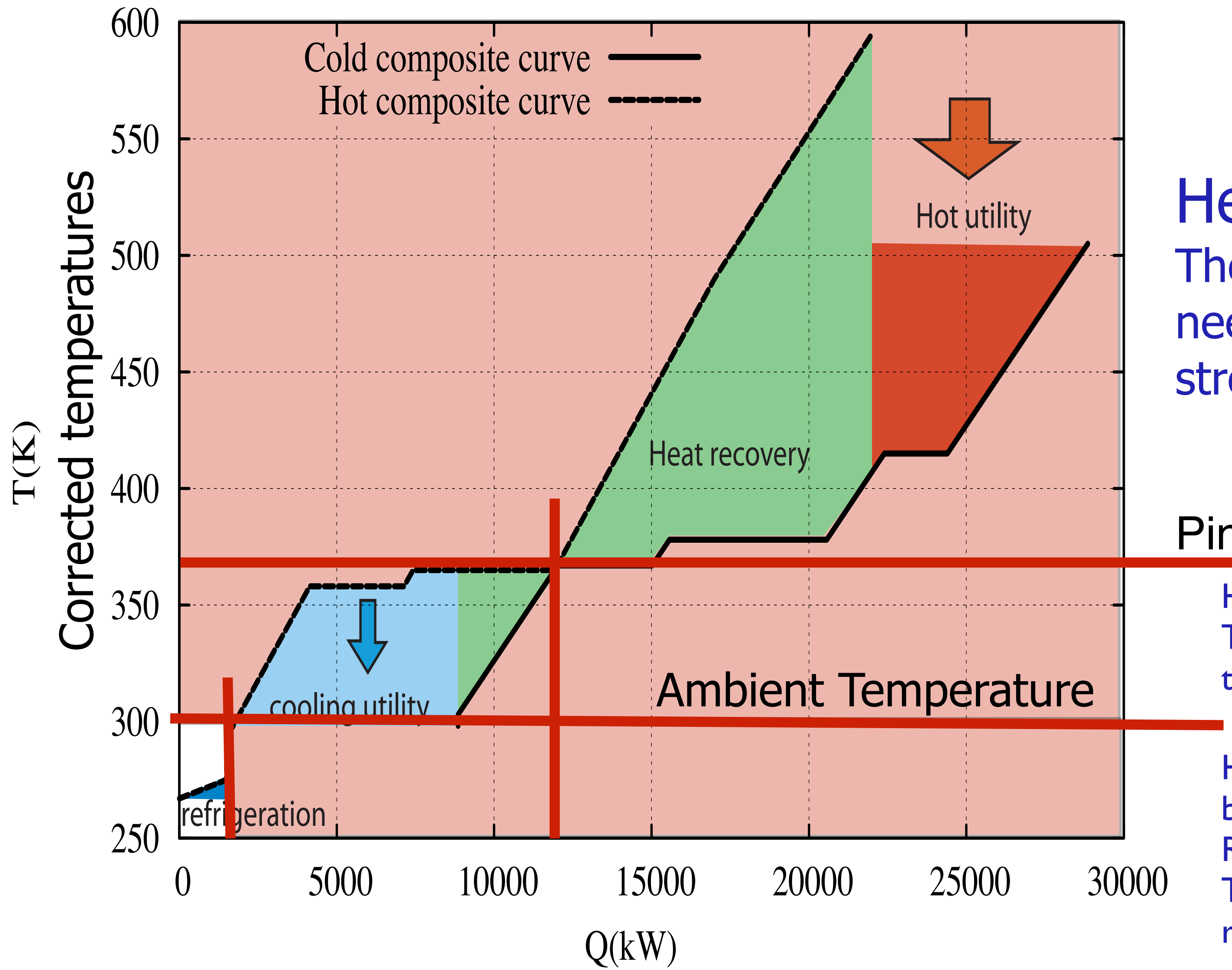
Pinch point temperature

Heat source

The heat to the cold streams is supplied by the hot streams below the pinch

The ambient temperature is important because below the ambient temperature, cooling means refrigeration and therefore needs a device to heat from below the ambient temperature to release the heat in the environment

3 Independent sub-systems



Heat sink

The heat of hot streams is needed to preheat the cold streams above the pinch

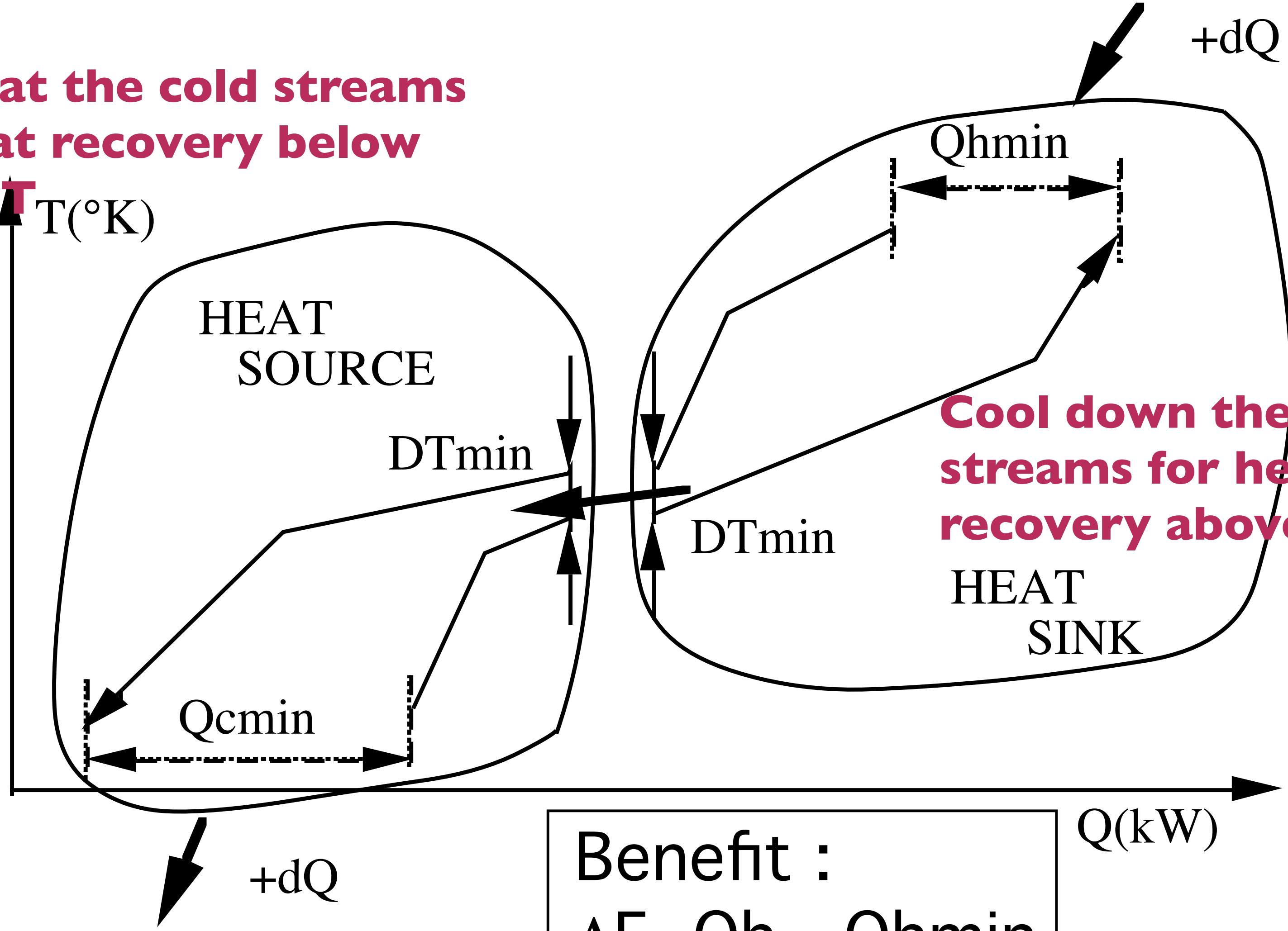
Pinch point temperature

Heat source
The cold streams are heated by the hot streams

Heat source
below ambient temperature
REFRIGERATION
The cold streams can supply refrigeration by heat recovery

The more in - the more out

Preheat the cold streams by heat recovery below pinch T

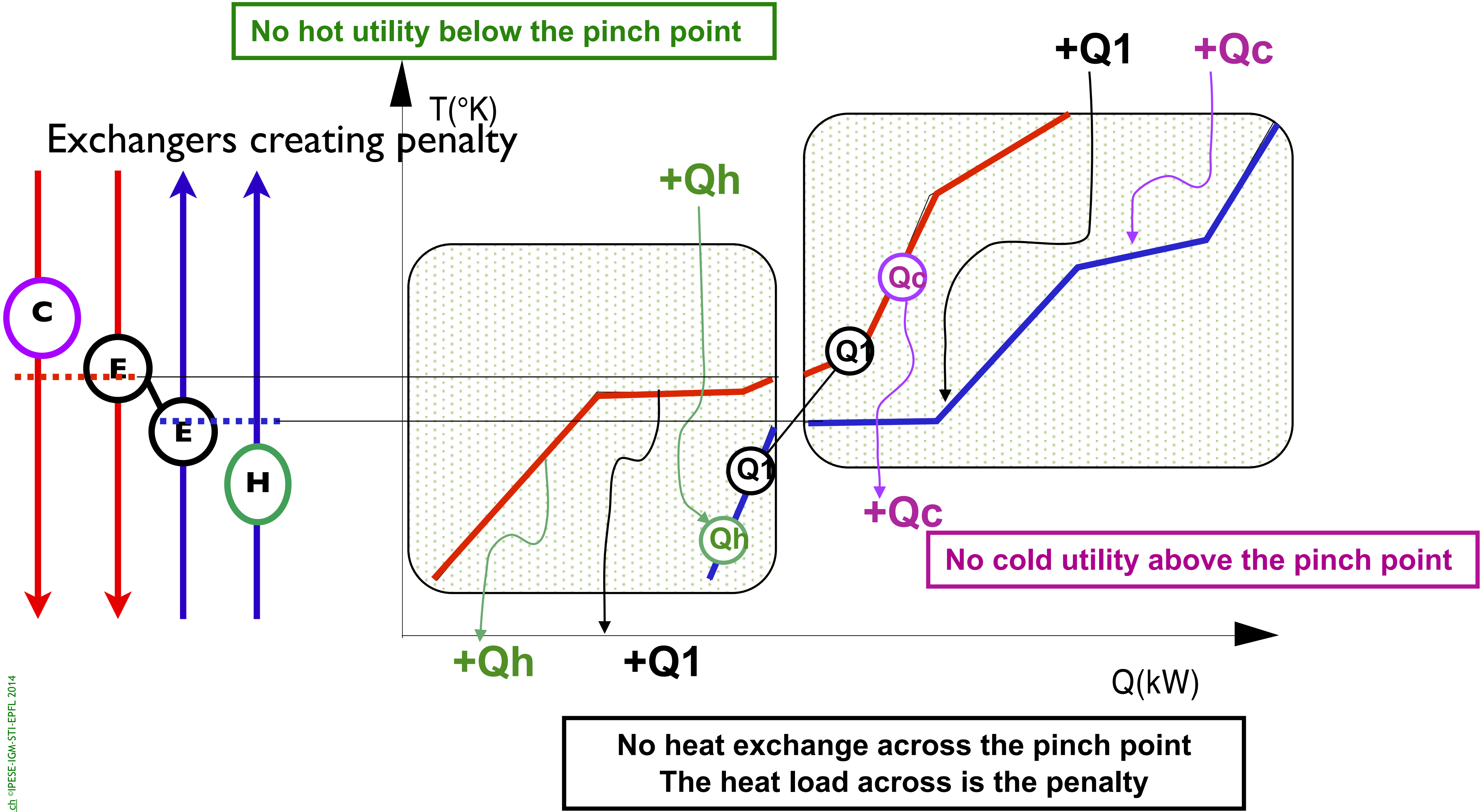


Cool down the hot streams for heat recovery above pinch T

Benefit :
ΔE=Qh - Qhmin
ΔE=Qc - Qcmin

QH-QC = Constant !

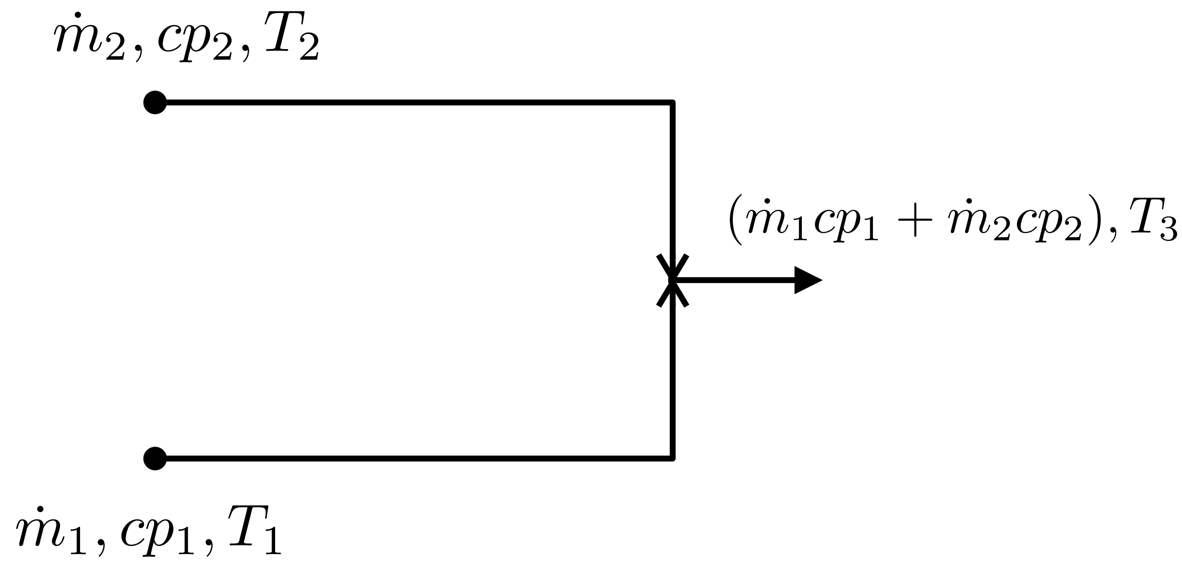
Penalizing heat exchangers

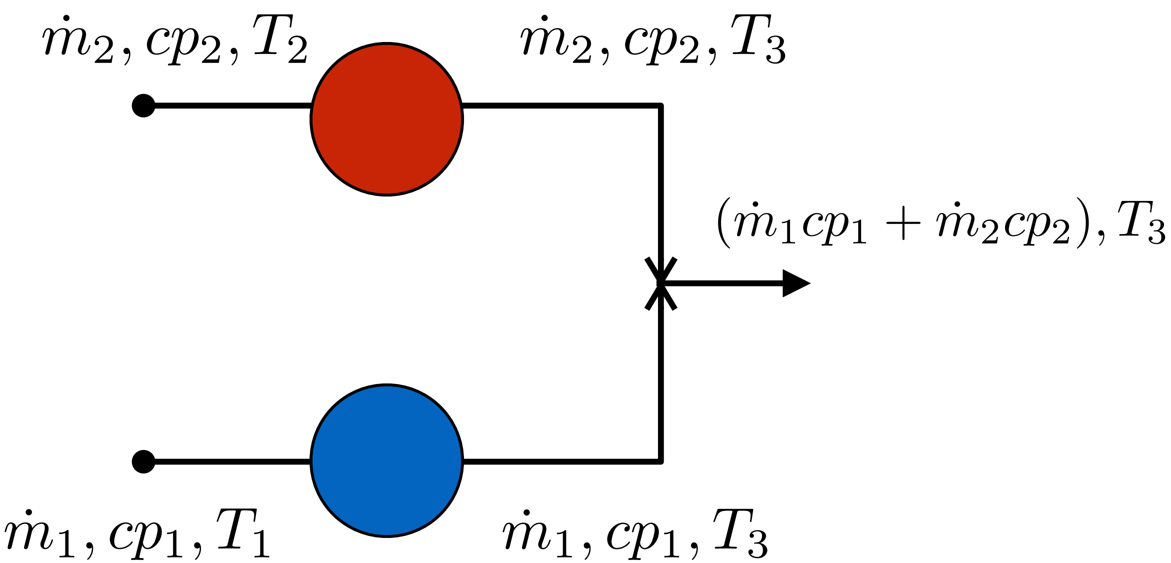


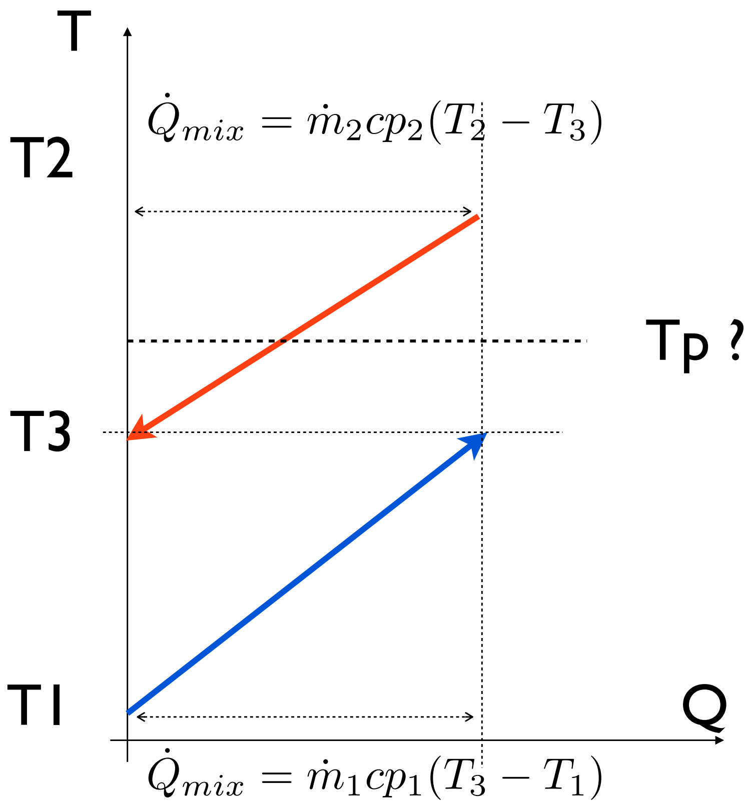
There are 3 types of penalising heat exchanges

1. a cold utility is used to cool a hot stream above the pinch. Above the pinch, this heat has to be used for heat recovery. One has to identify a cold stream above the pinch to cool the identified hot stream.
2. a hot utility that is used below the pinch. Below the pinch there is enough heat in the hot stream to preheat all the cold stream with a hot utility. One has to identify the hot stream below the pinch to supply the heat to the cold stream so that it reaches the pinch temperature.
3. a heat exchanger that is preheating a cold stream below the pinch with a hot stream above the pinch. The heat of the hot stream is indeed needed to preheat a cold stream above the pinch. In such a case, one has to identify a cold stream above the pinch to cool down the hot stream above the pinch and to identify a hot stream below the pinch to preheat the cold stream below the pinch

Mixing unit is a heat exchanger



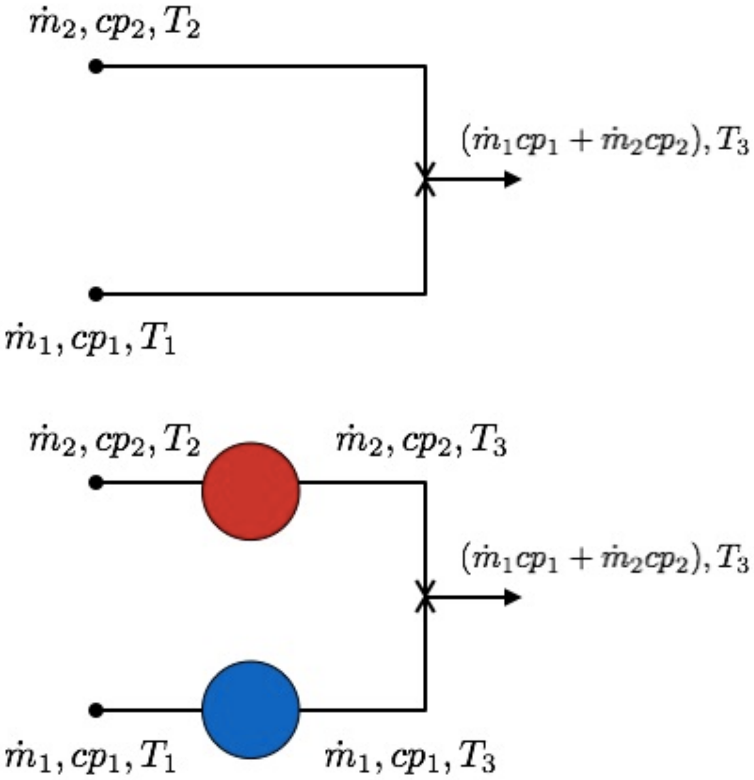


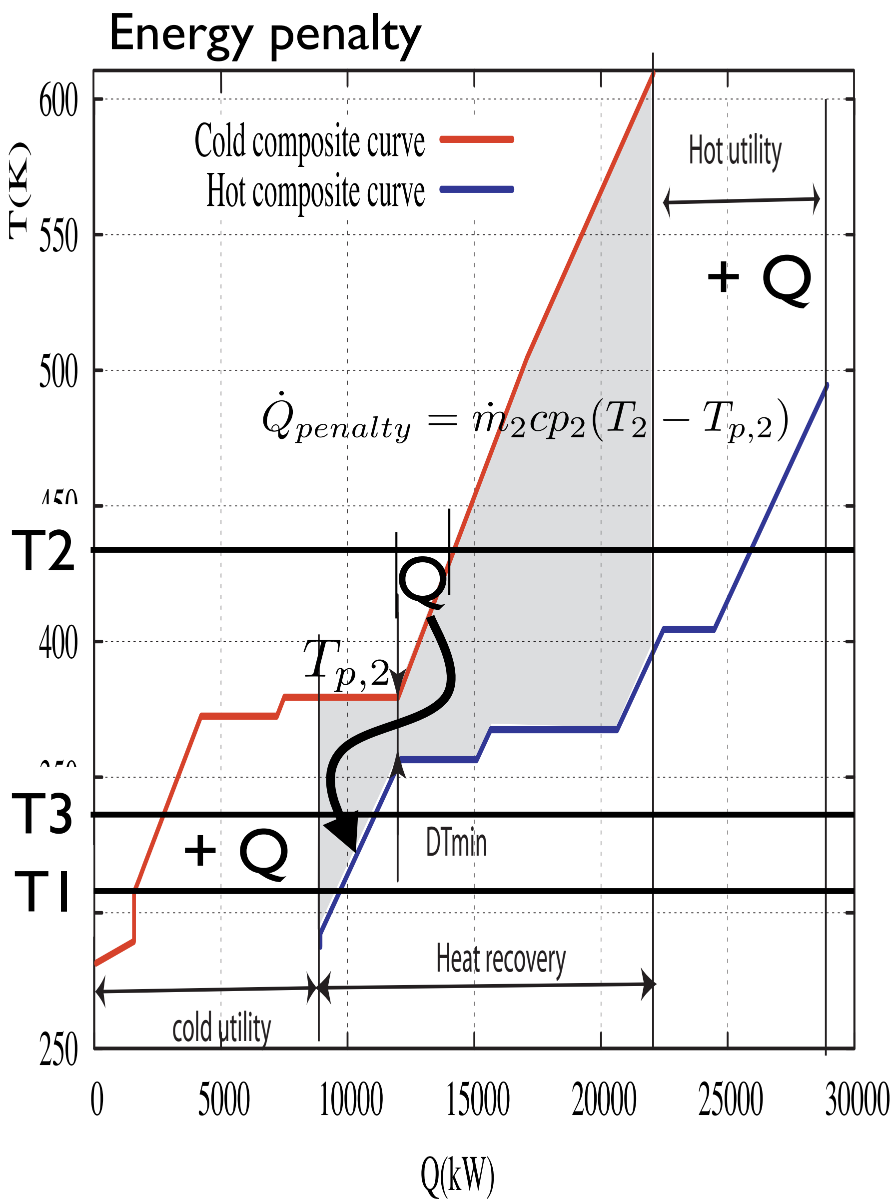


Mixer are hidden heat exchangers, when well positioned (all temperatures above or below the pinch) they are cheap heat exchangers. When one of the 3 temperatures is on the other side of a pinch, the mixer is penalising. In the example above the heat of the hot stream above the pinch Tp is needed to heat a cold stream above the pinch. After the heat recovery it can be send to the mixer with the cold stream that should have been preheated by a hot stream below the pinch.

Penalizing mixing unit

- Mixing





The penalty is the heat load above the pinch, it is needed to identify both the new exchange above the pinch to recover the heat to preheat the cold stream AND the heat recovery to preheat the cold stream below the pinch.

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  - Heat cascade => Grand composite curve
- **Pinch point**
  - Penalizing heat exchangers
  - 3 zones
- **More-in - More-out principle**