Process development
Process conditions and heat recovery

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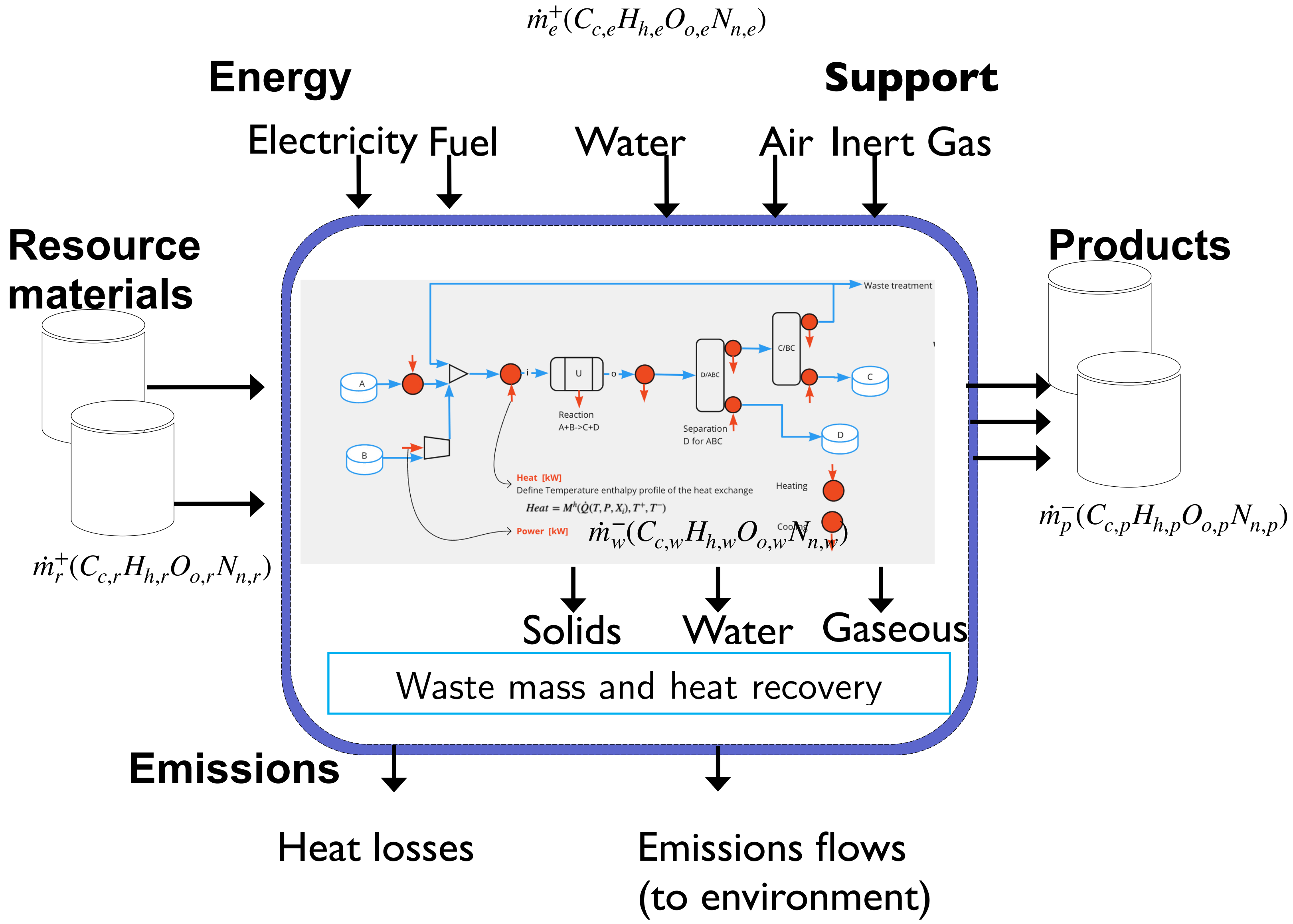
Engineering

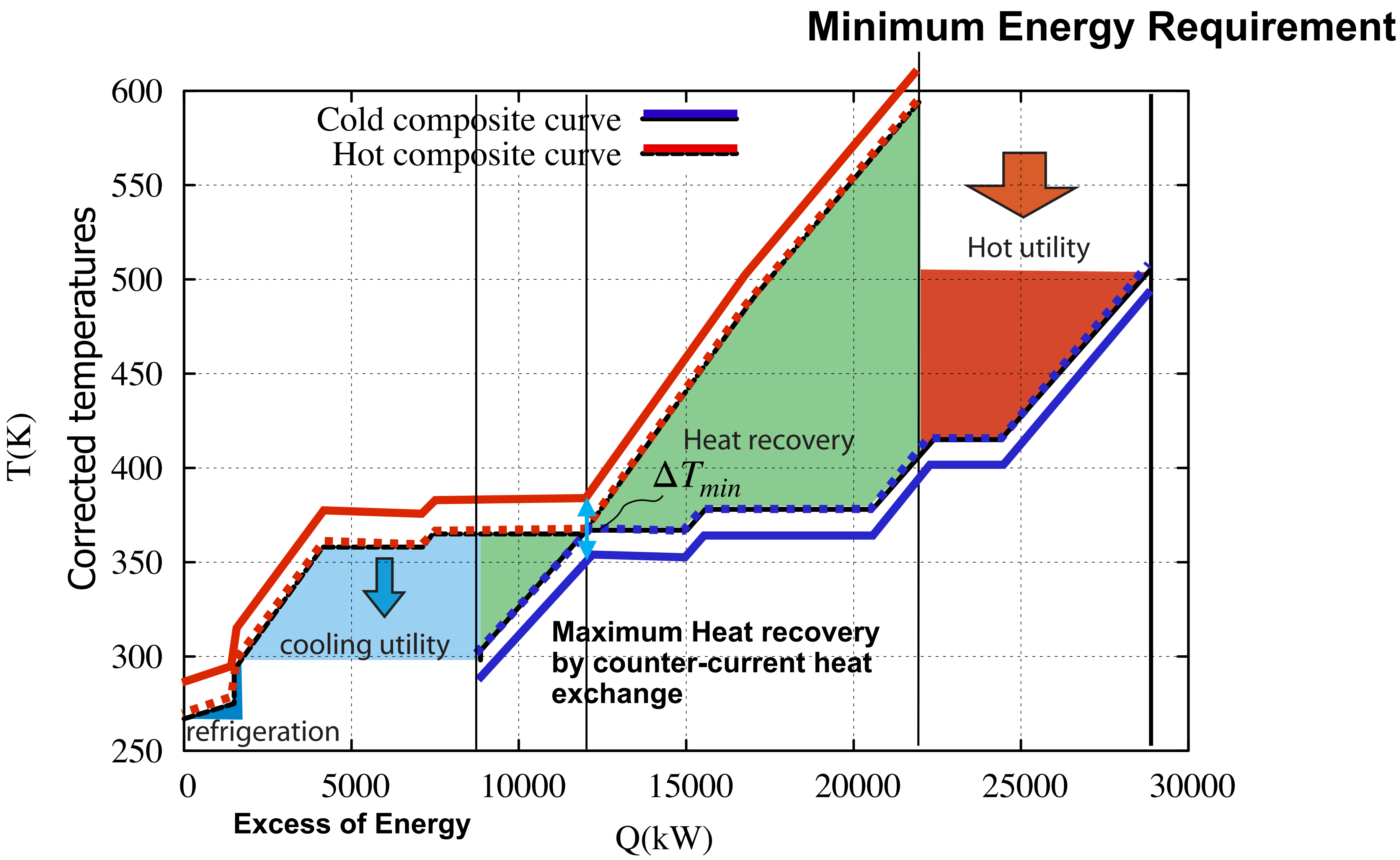
Where are we ?

- ✓ Heat recovery potential
  - ✓ ΔT_{min} : minimum approach temperature for heat recovery
  - ✓ Heat recovery by composite curves
- ✓ Energy conversion to close the energy balance
  - ✓ Choose the resource
  - ✓ Conversion technologies
    - ✓ Heat supply & distribution
    - ✓ Cogeneration
    - ✓ Heat pumping
    - ✓ Refrigeration
- Changing the process conditions
  - Plus-Minus + Heat pumping
- Exergy analysis of the energy conversion system

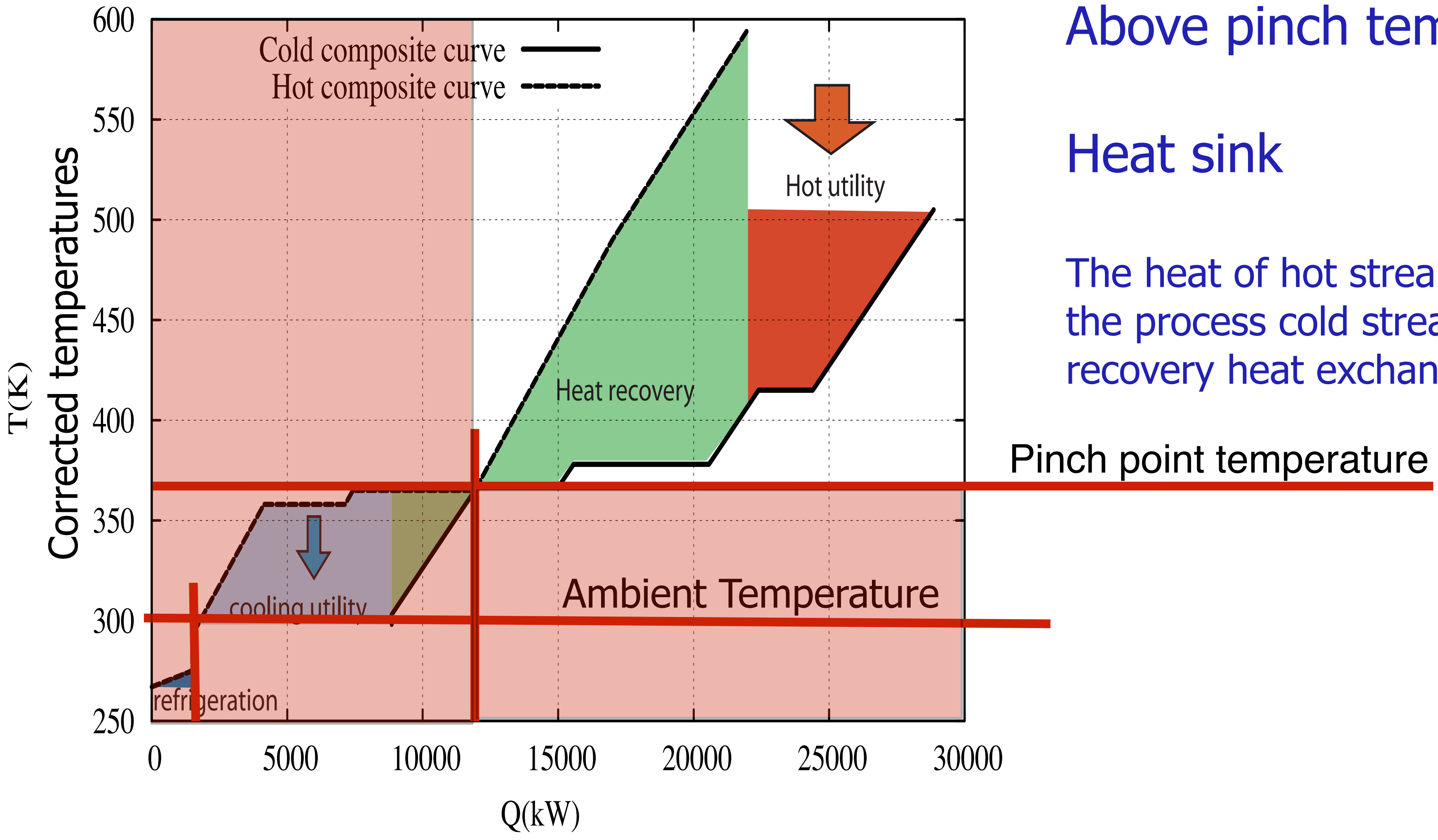
Process system boundaries



Maximum heat recovery Target with ΔT_{min} assumption



3 Independent sub-systems

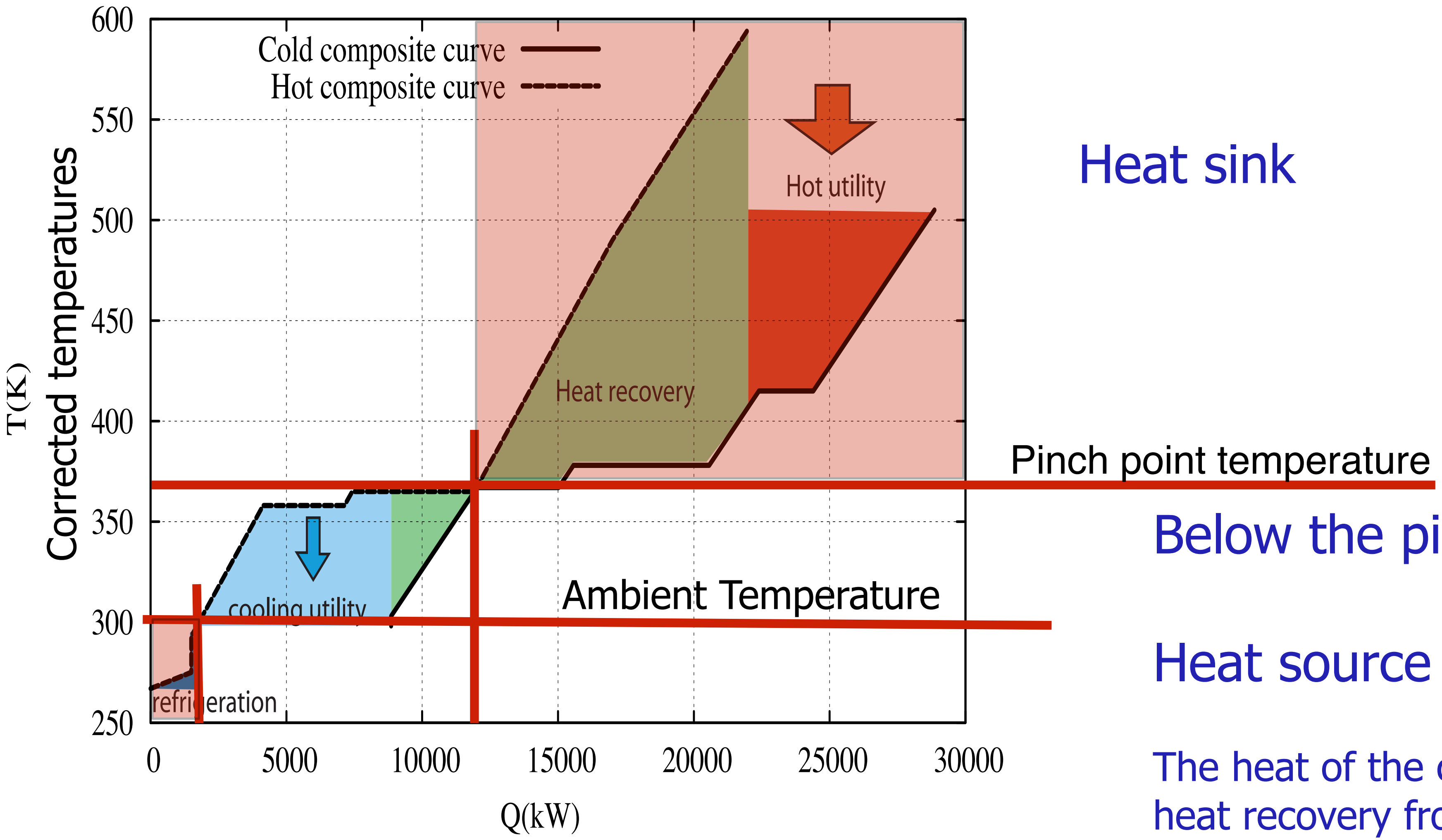


Above pinch temperature

Heat sink

The heat of hot streams is used by the process cold streams in heat recovery heat exchangers

3 Independent sub-systems



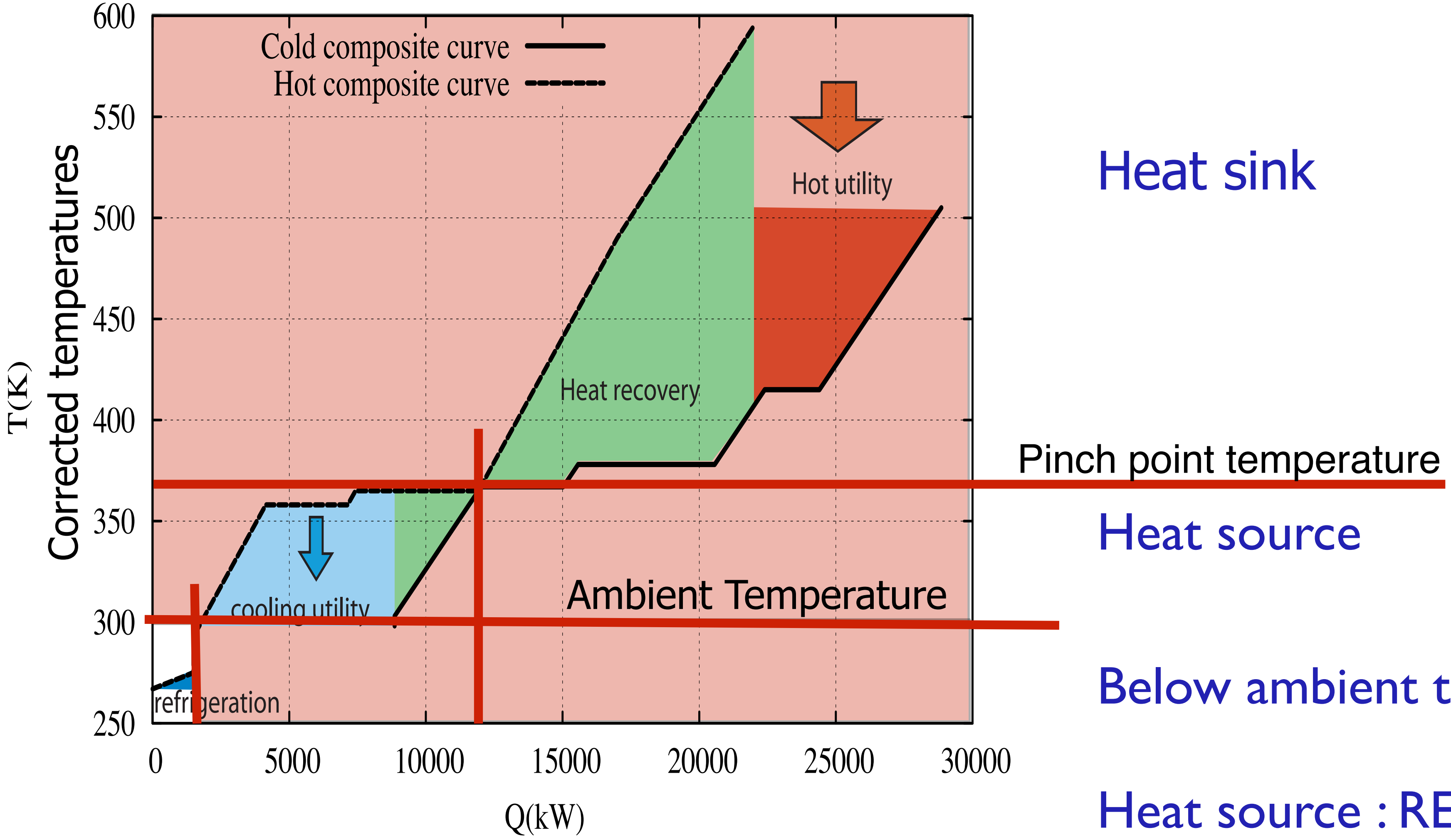
Heat sink

Below the pinch/Above ambient

Heat source

The heat of the cold streams is supplied by heat recovery from the process hot streams

3 Independent sub-systems



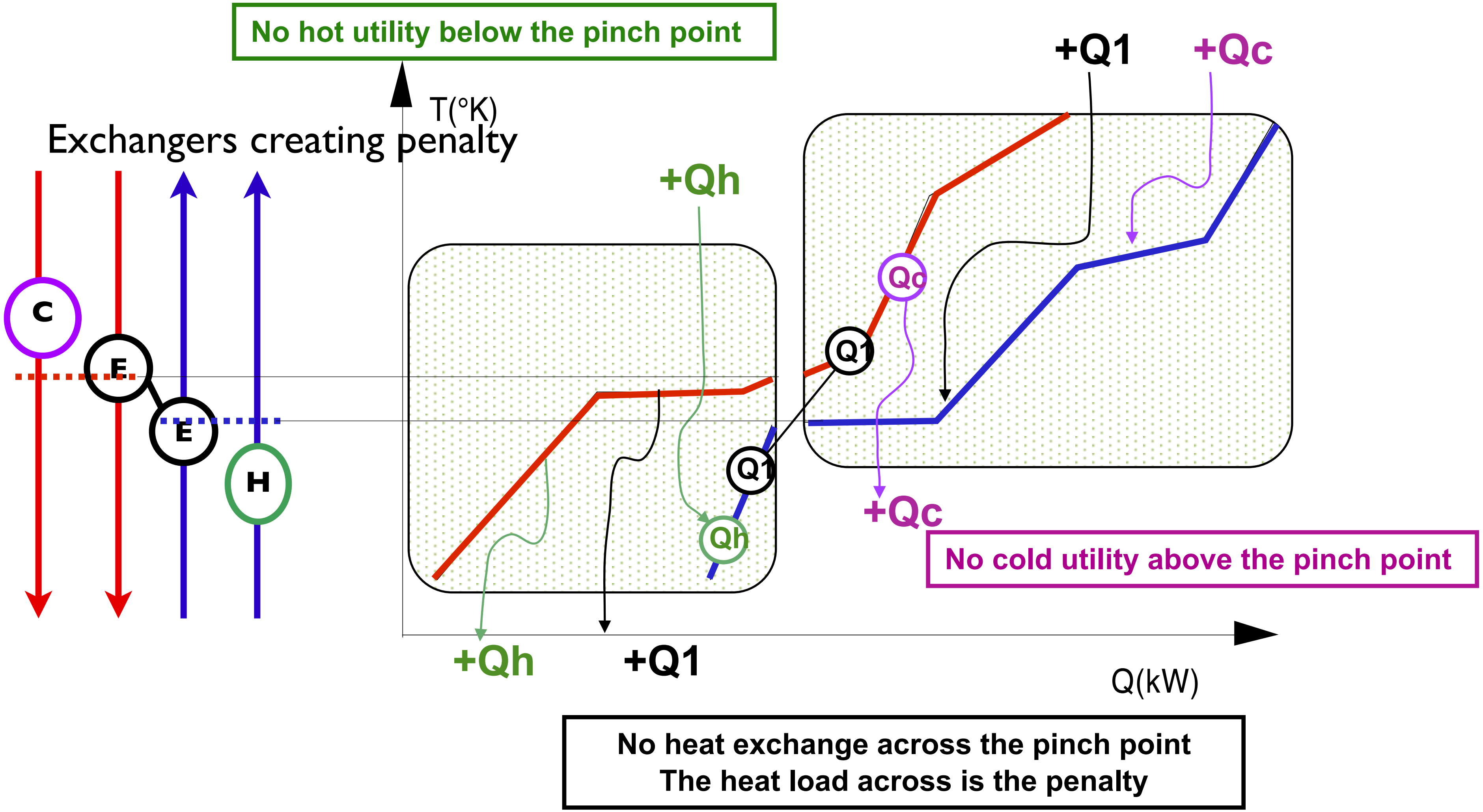
Heat sink

Heat source

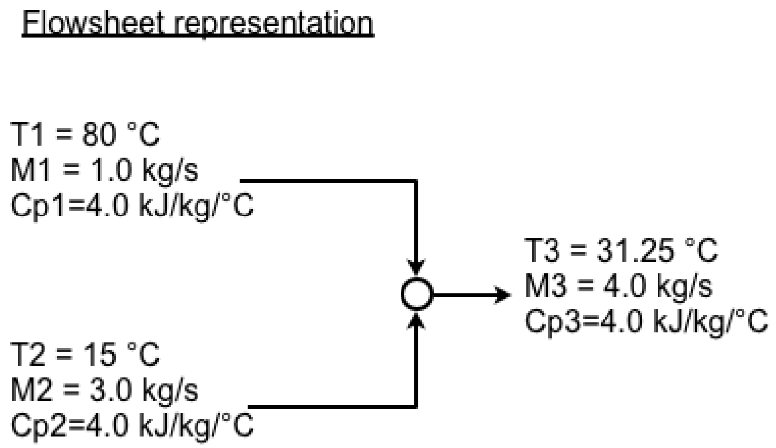
Below ambient temperature

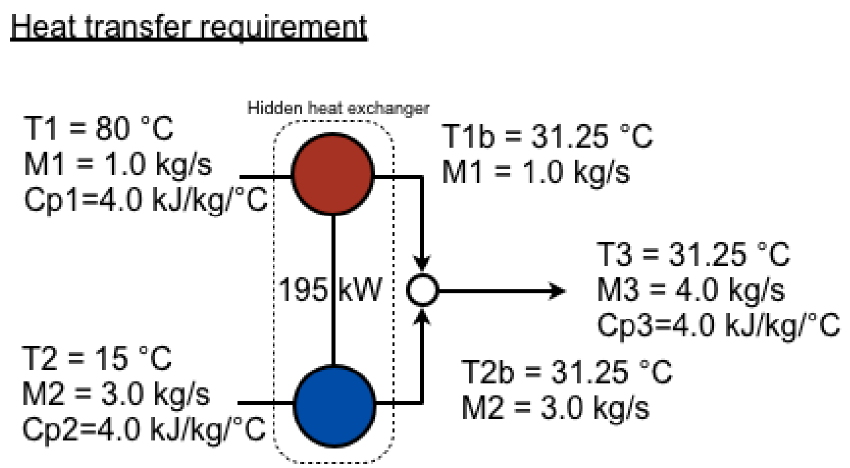
Heat source : REFRIGERATION
The cold streams can supply refrigeration by heat recovery

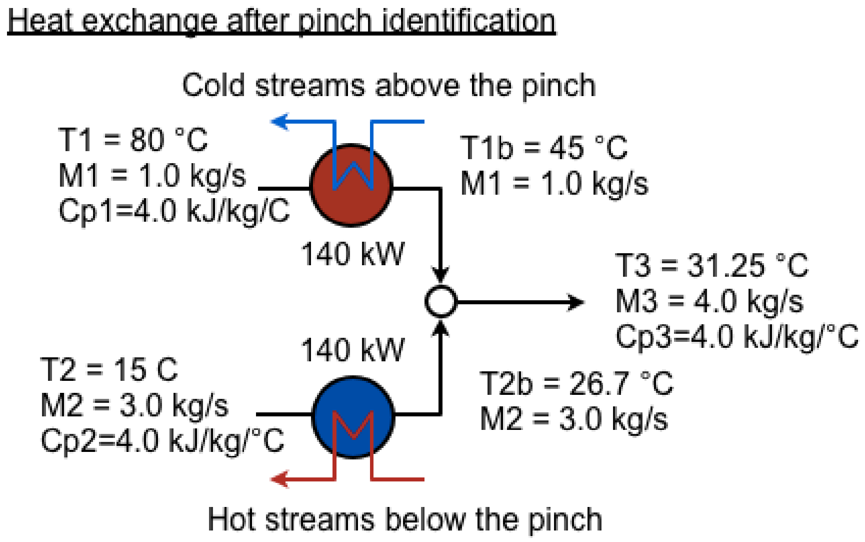
Penalizing heat exchangers

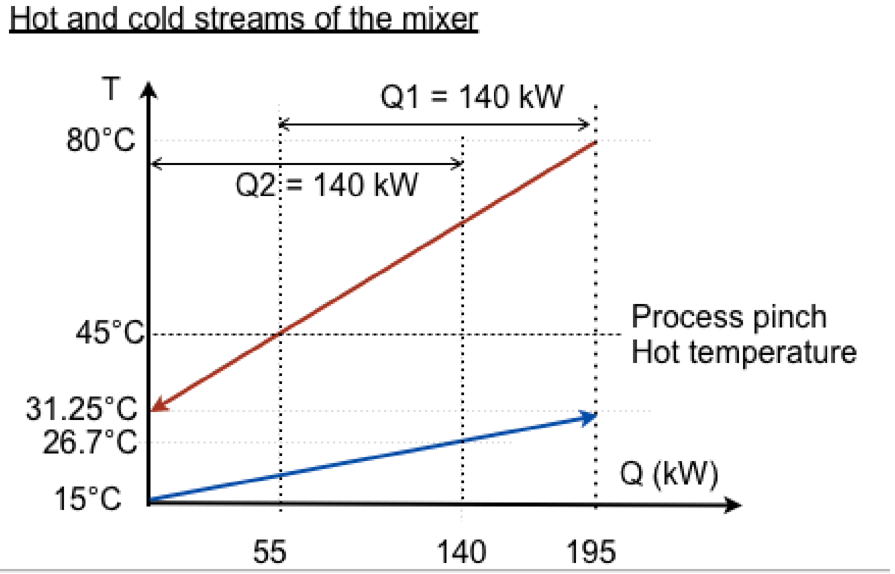


Mixers may be penalising heat exchangers



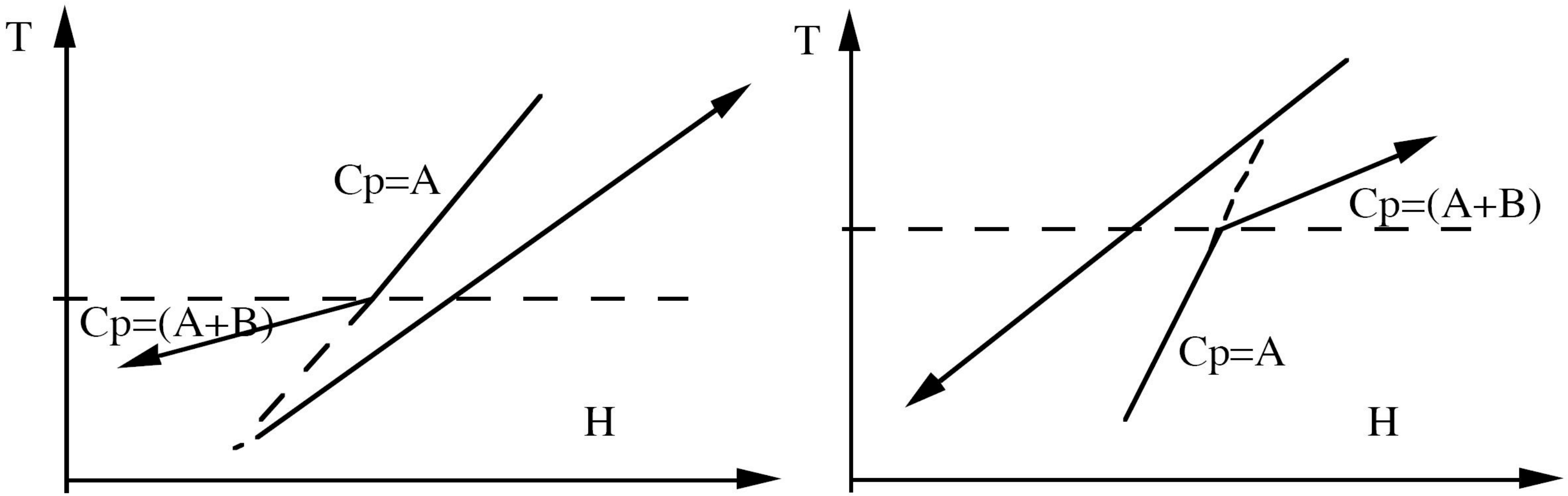






Who is creating a pinch point ?

- Pinch are always created by inlet conditions of a stream (or a change of slope, when the H-T profile is not linear)

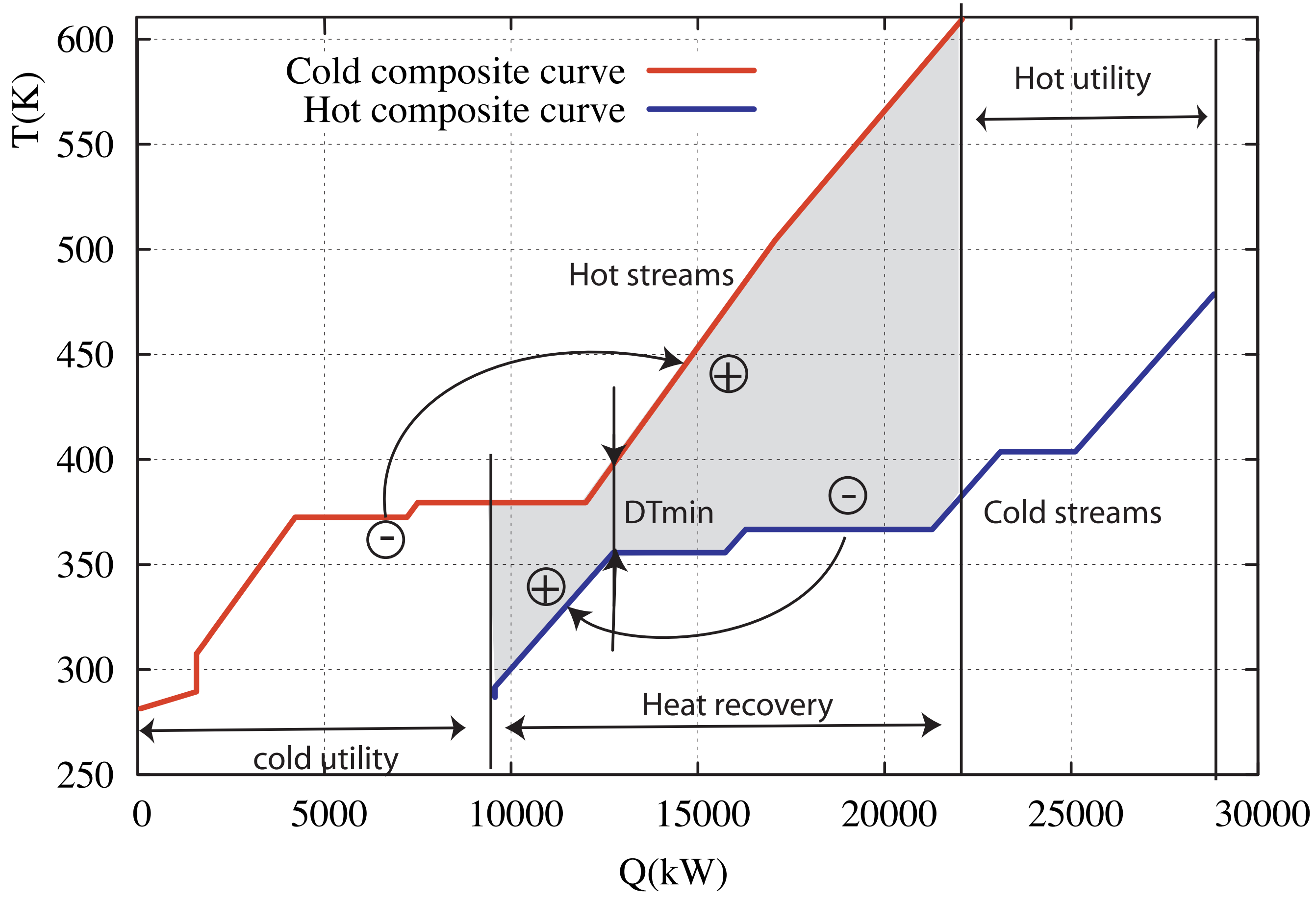


(a) Hot streams (b) Cold streams

Plus - Minus principle : Increasing the heat recovery potential

Across the pinch

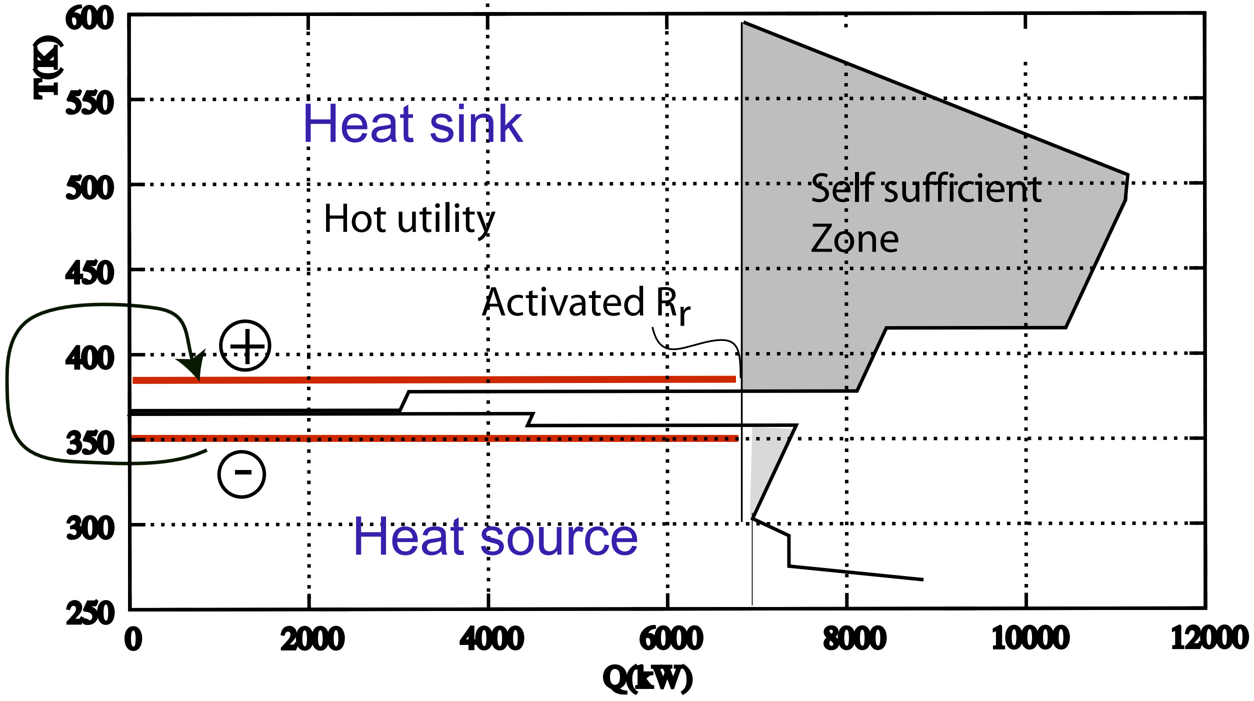
Transfer hot streams from below to above the pinch : to allow them supply heat to the cold streams above the pinch where there is a heat deficit



Transfer cold streams from above to below the pinch : to allow them recover heat from the excess of heat in the hot streams below the pinch

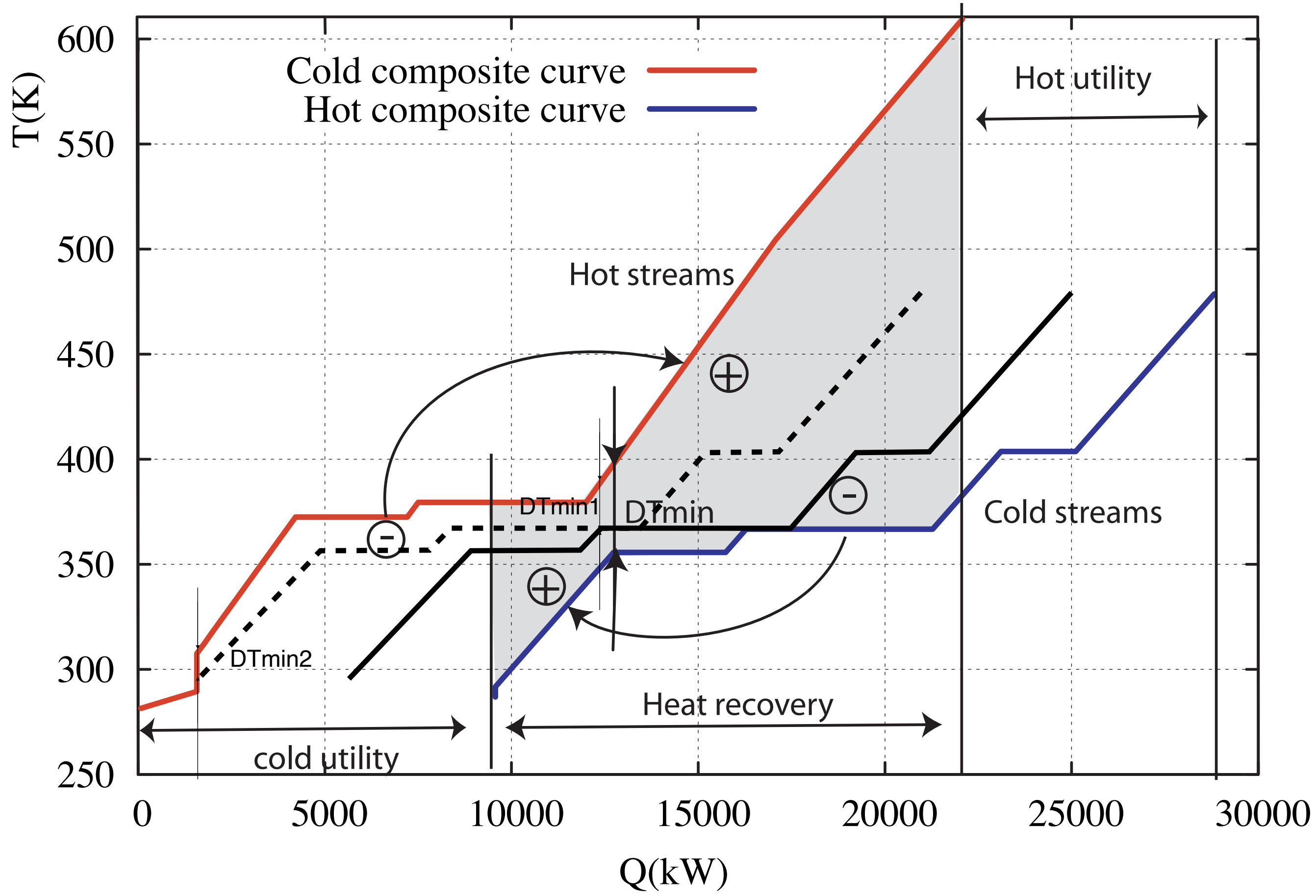
Grand composite analysis (Heat cascade)

- The overall balance is not changed !
  - Hot streams from below to above the pinch
  - Cold streams from above to below
  - $\dot{Q}$ limited by the creation of a new pinth point



Plus - Minus principle : possible action 1

Modify the ΔT_{min} assumption



1. Change $\Delta T_{min}/2$ of hot or cold
2. Recalculate the heat recovery potential: ΔMER
3. Calculate cost balance

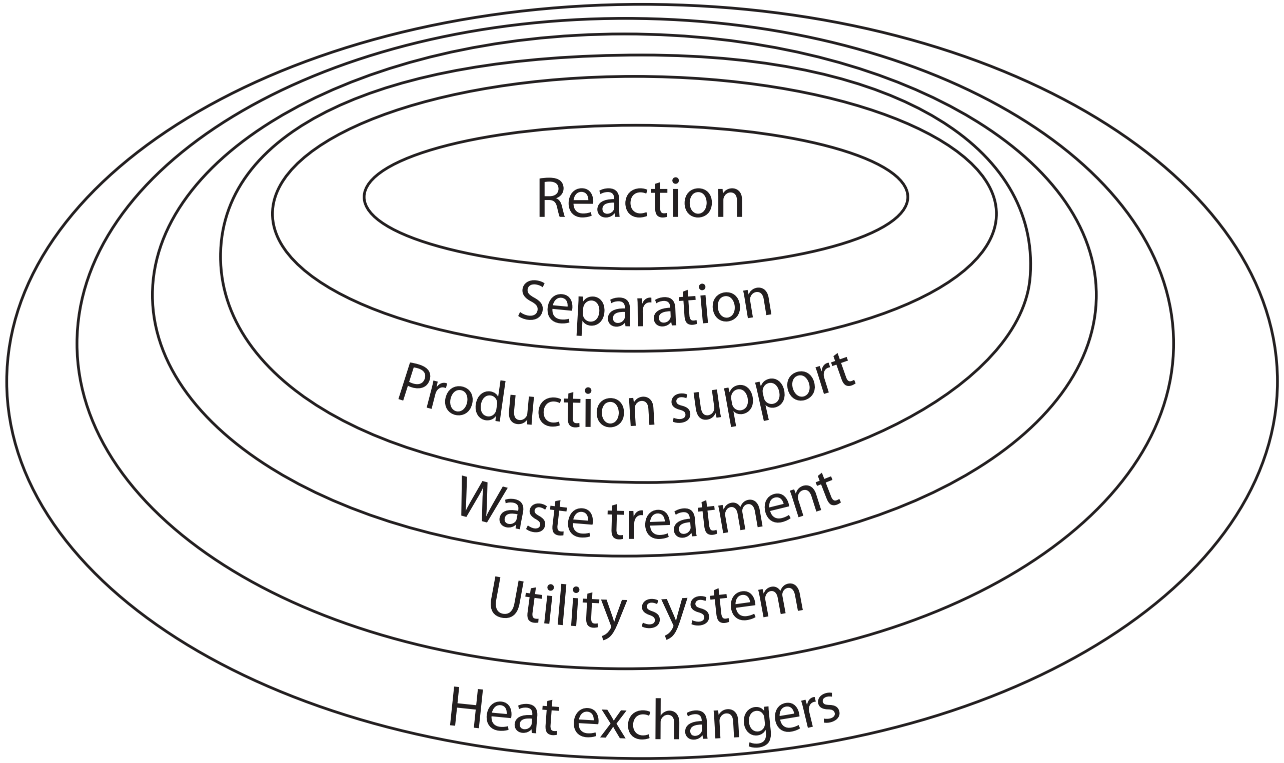
$$-\Delta MER \cdot v^{+}_{heat} \cdot t_{op} \geq \frac{1}{\tau} \cdot \Delta I_{HEN}(A_{HEN})$$

with $\Delta I_{HEN}(A_{HEN})$ additional heat exchanger network investment

$\Delta MER \cdot v^{+}_{heat} \cdot t_{op}$ savings in operating cost

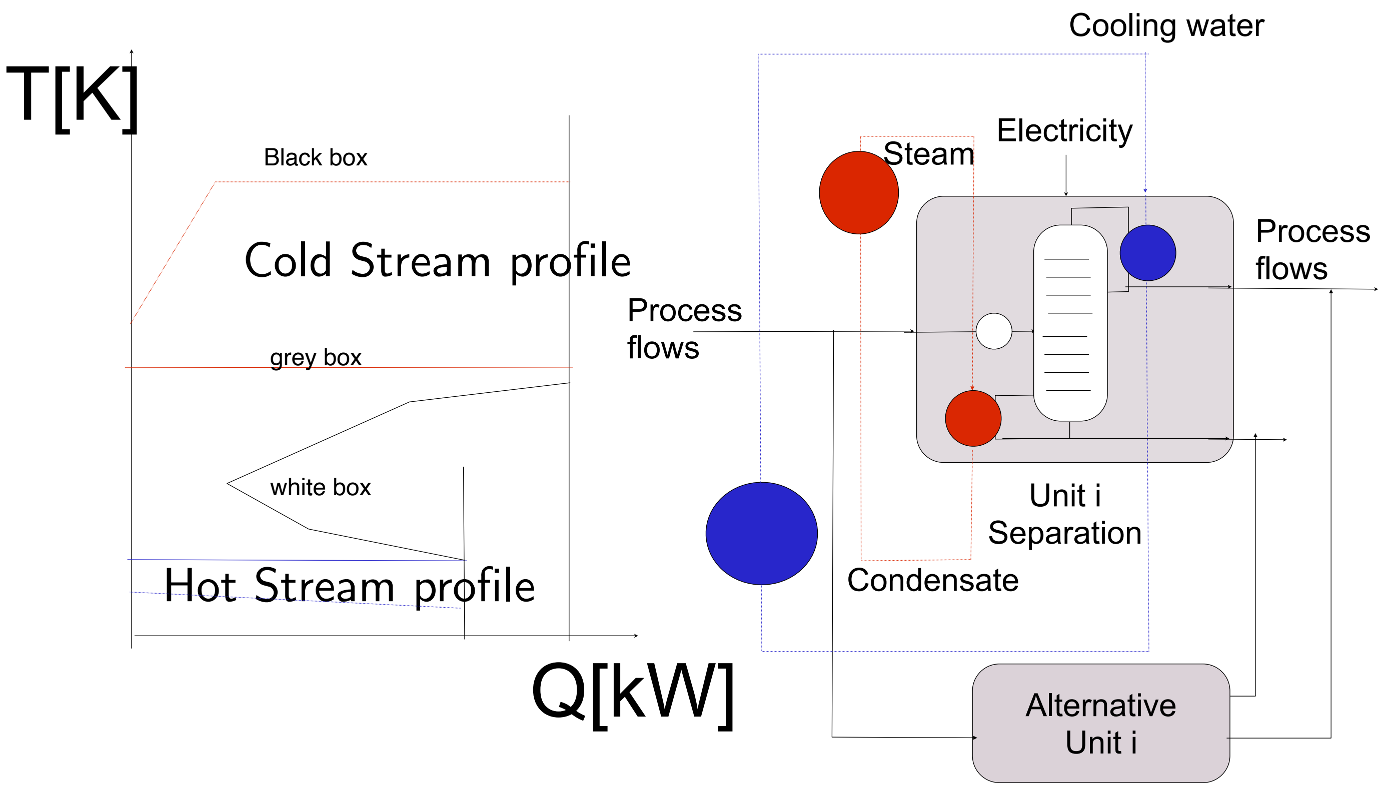
Onion diagram

- Hierarchy in the process unit operations

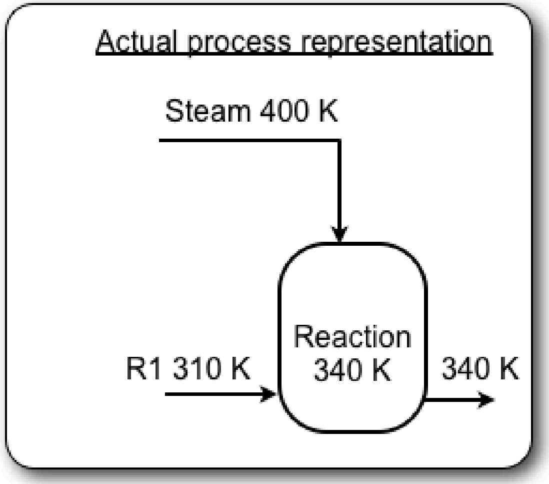


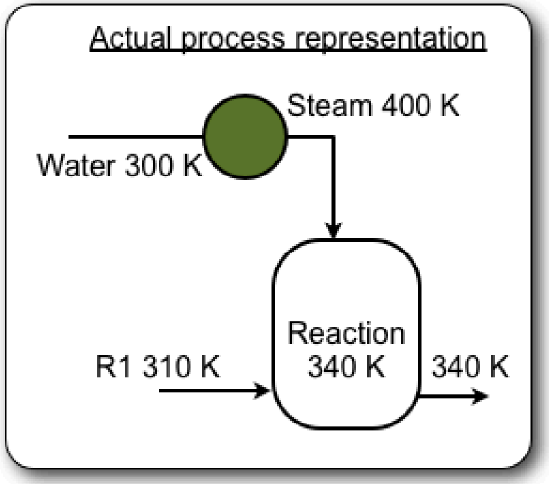
Heat transfer interfaces of unit operations

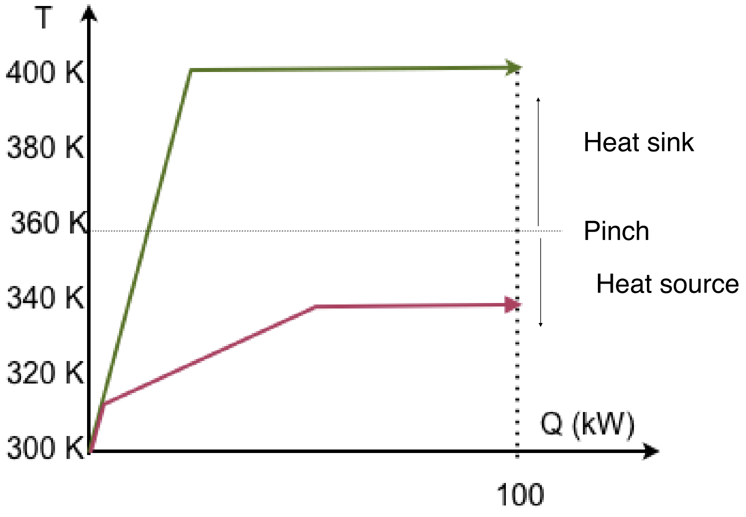
- Same unit operation : different heating and cooling profiles
- Process engineering analysis of the role of heating and cooling for the unit operation

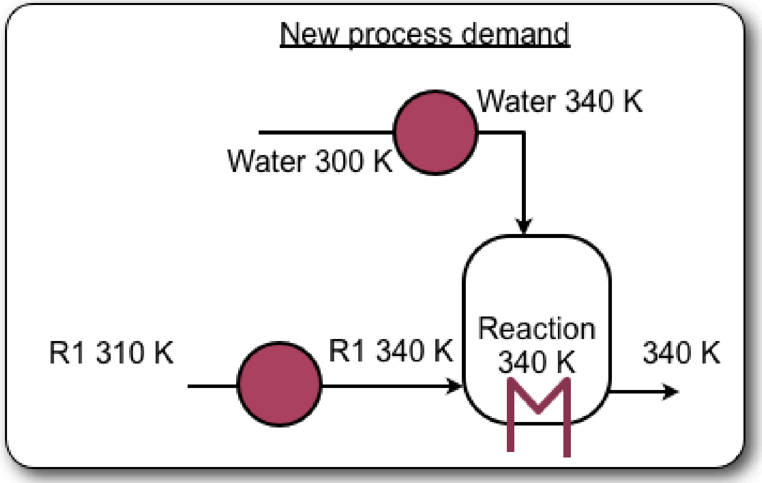


Changing the process demand interface





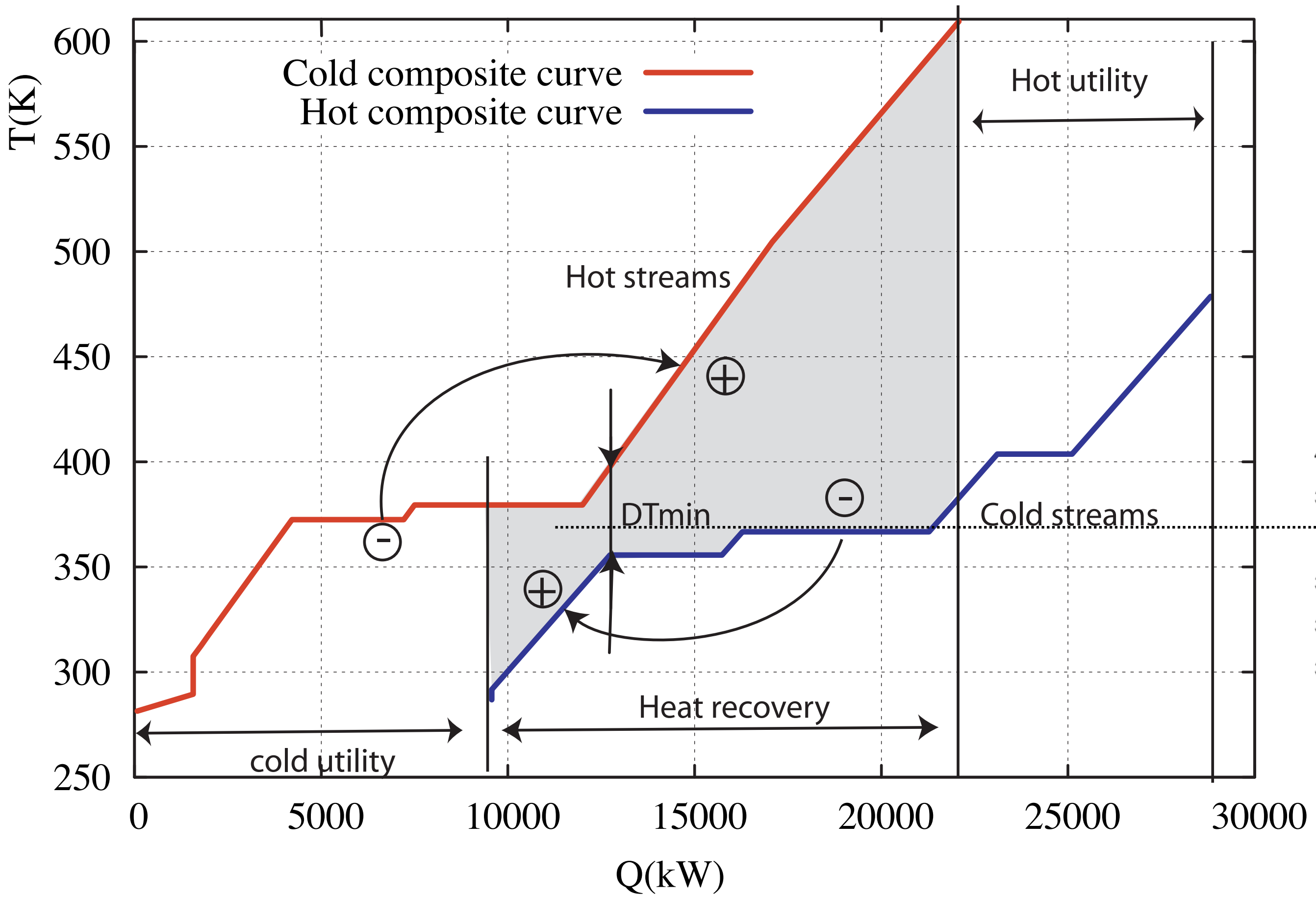


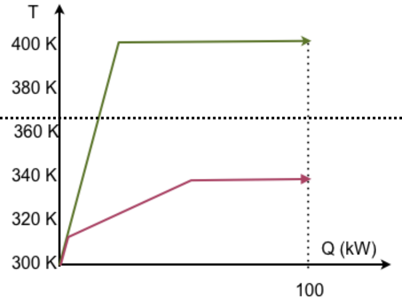


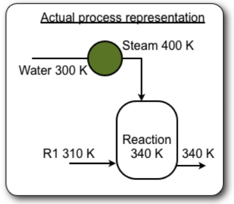
Changing the process demand profile allows to change the temperature at which the heat is asked or made available by a process operation

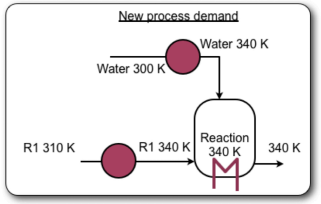
Plus - Minus principle : change the heat requirement

Transfer hot streams from below to above the pinch : to allow them supply heat to the cold streams above the pinch where there is a heat deficit





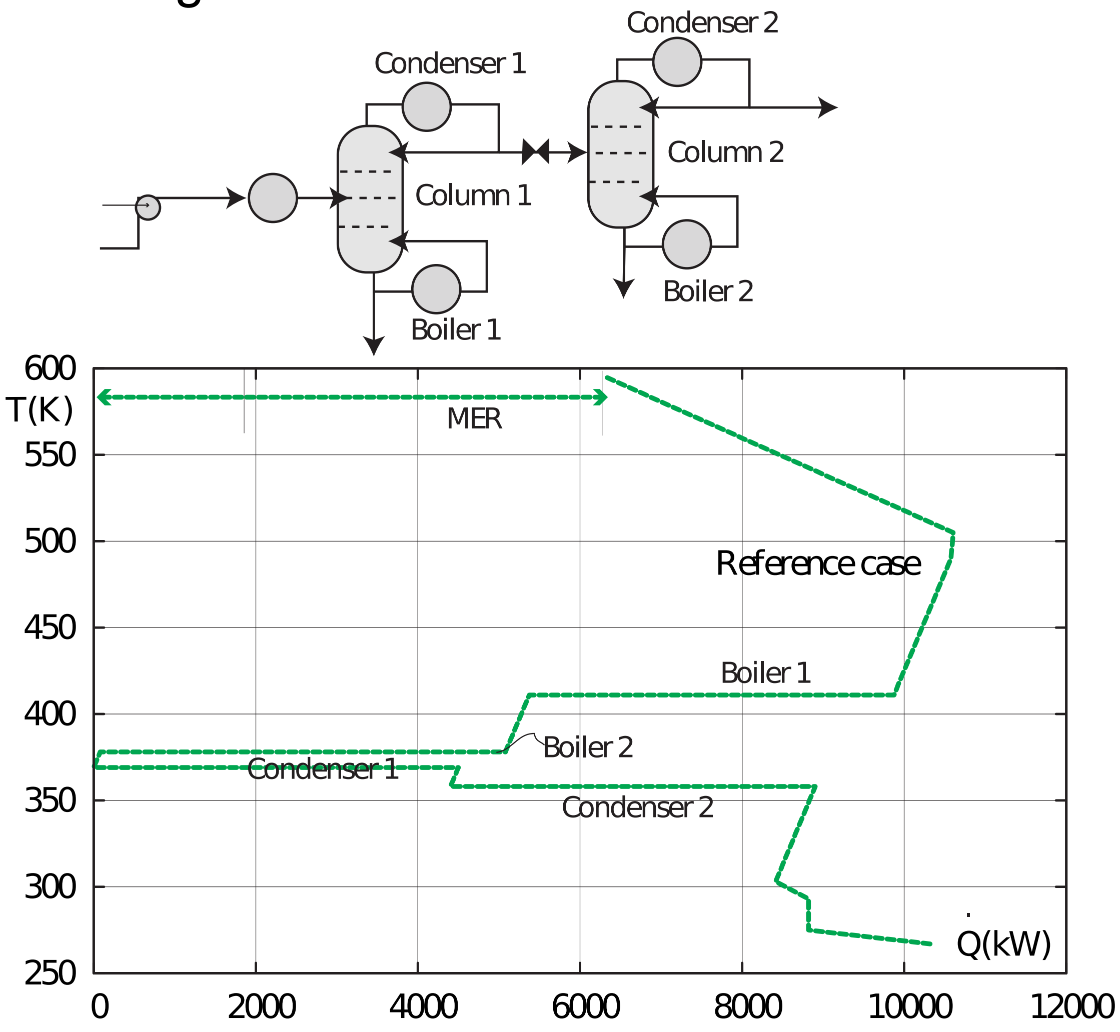




Transfer cold streams from above to below the pinch : to allow them recover heat from the excess of heat in the hot streams below the pinch

Changing the operating conditions

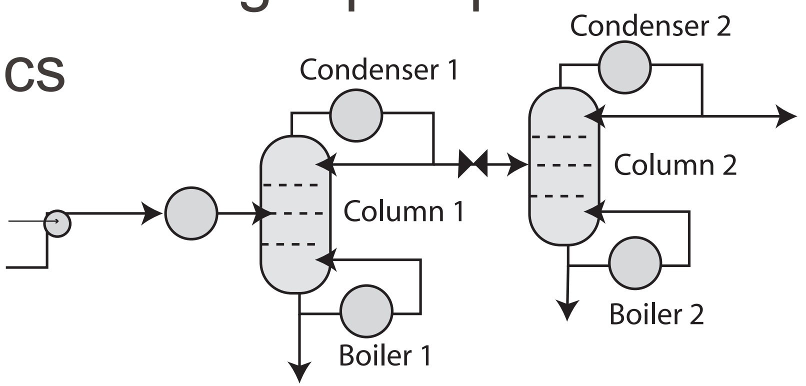
Heat integration of two distillation columns



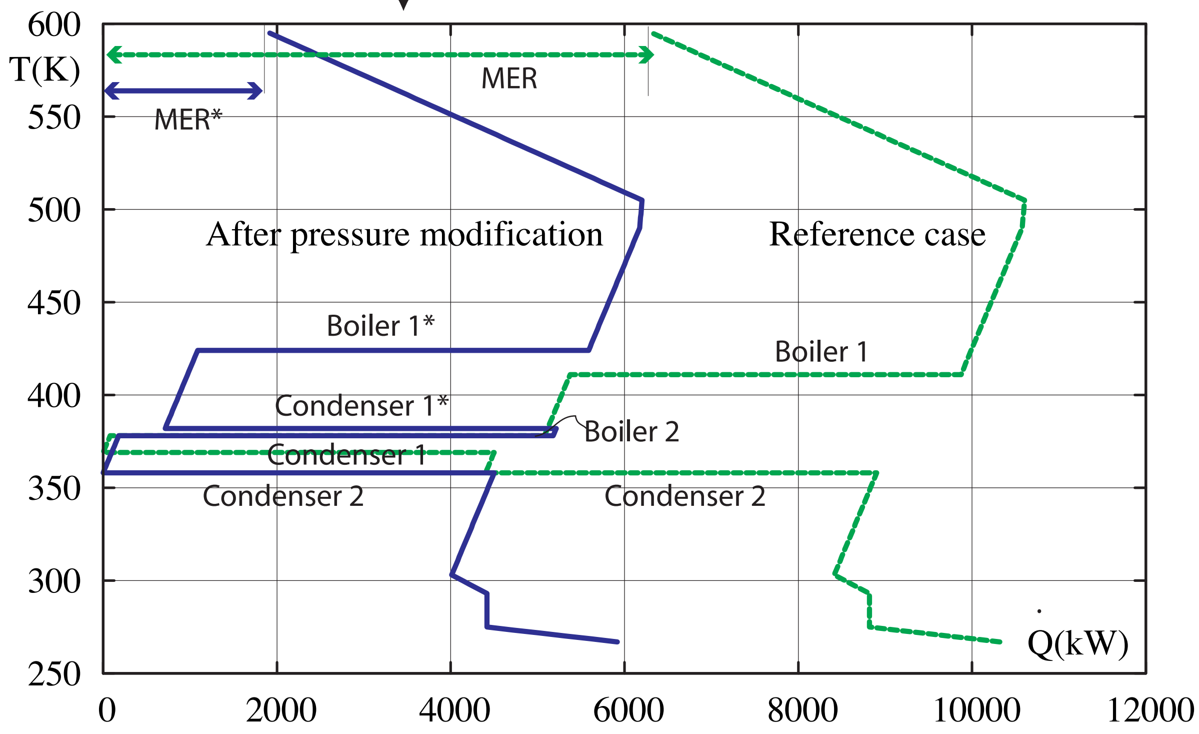
Column1 operates at P1 - Column 2 operates at P2 < P1

Example : two columns integration : pressure change

- Increase pressure of column 1 using a pump
- verify column hydrodynamics



* The heat of condensation in the condenser is higher when pressure is increased
* Choose the pressure so that the condenser 1 temperature is higher then the boiler 2 temperature

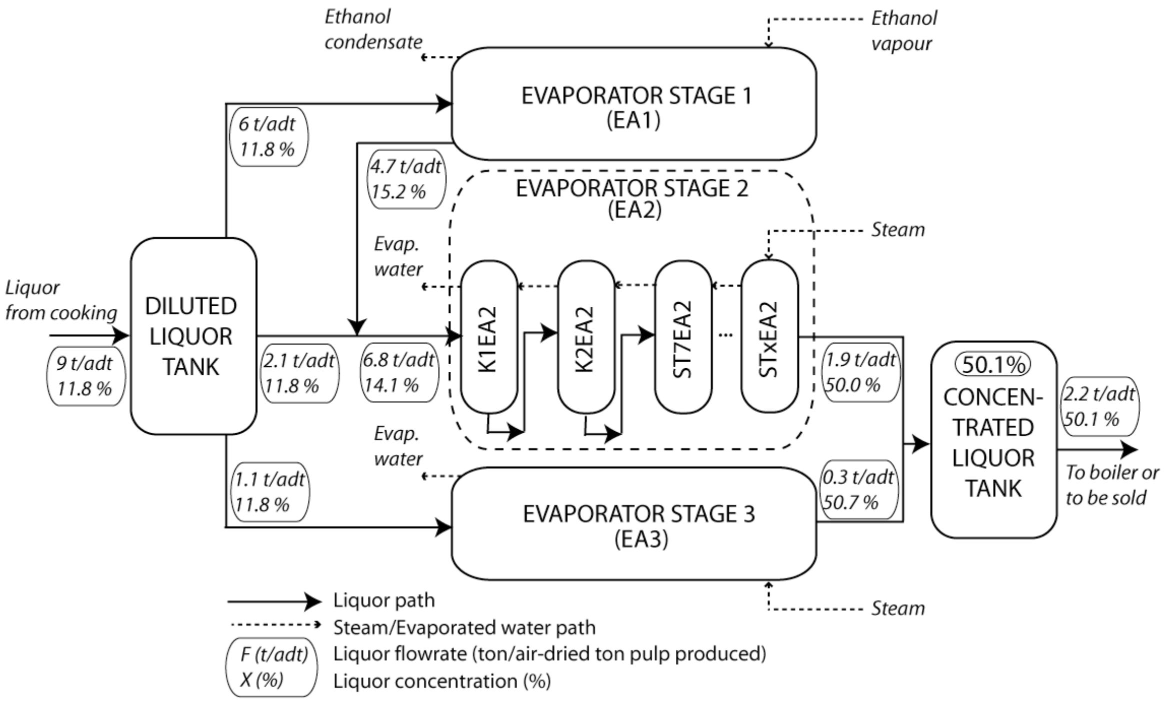


Modifying the process integration opportunities

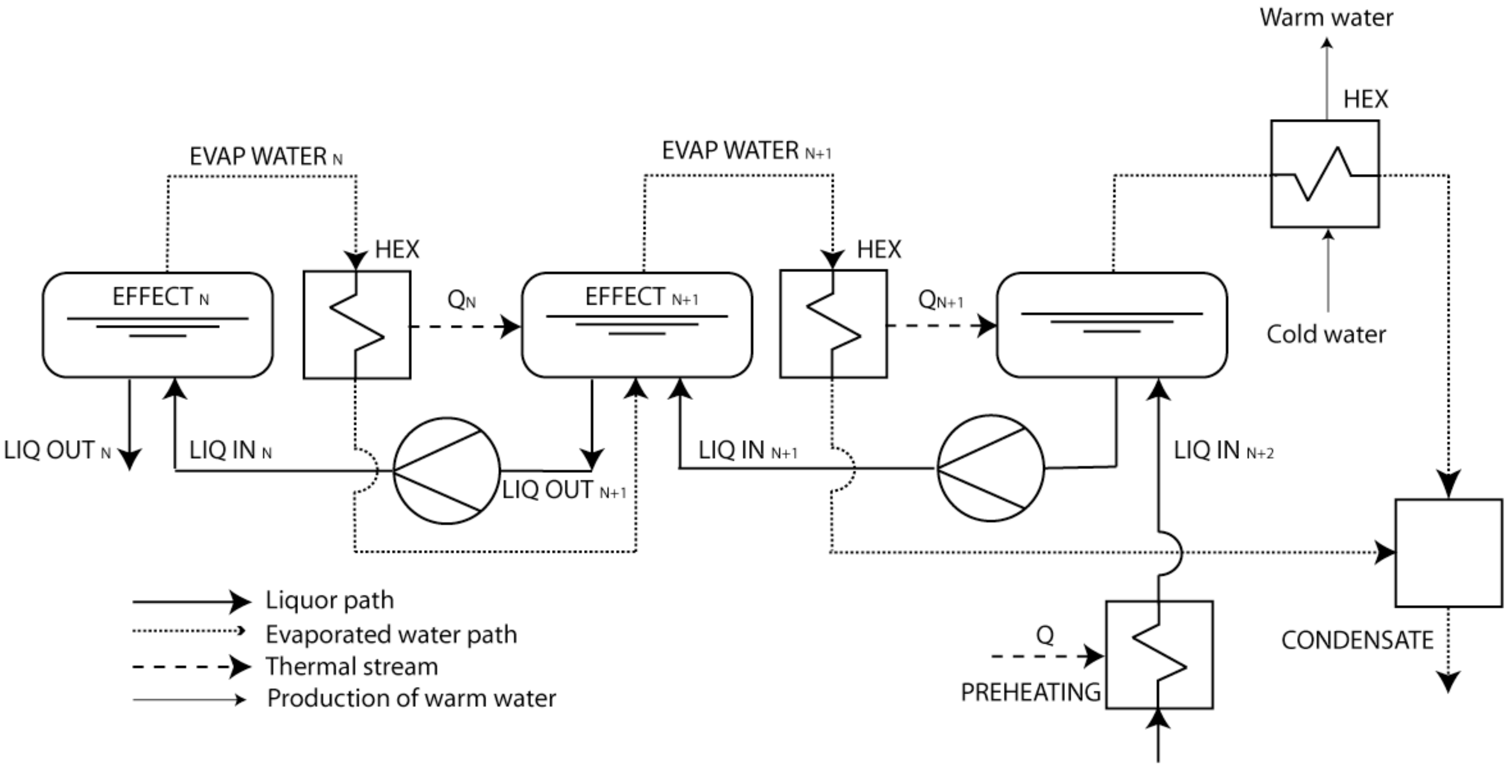
- Modify the process units heat transfer interface
- Modify the process units operating conditions
  - to increase the heat recovery potential
  - e.g. change the operating pressure of a unit
- Externally change the temperature of the requirement
  - Heat pumping/ expansion

Example 2 : the multi-effect evaporator

- Multi effect evaporators are used to
  - Concentrate liquid streams
  - are large steam consumers
  - food and pulp and paper industry

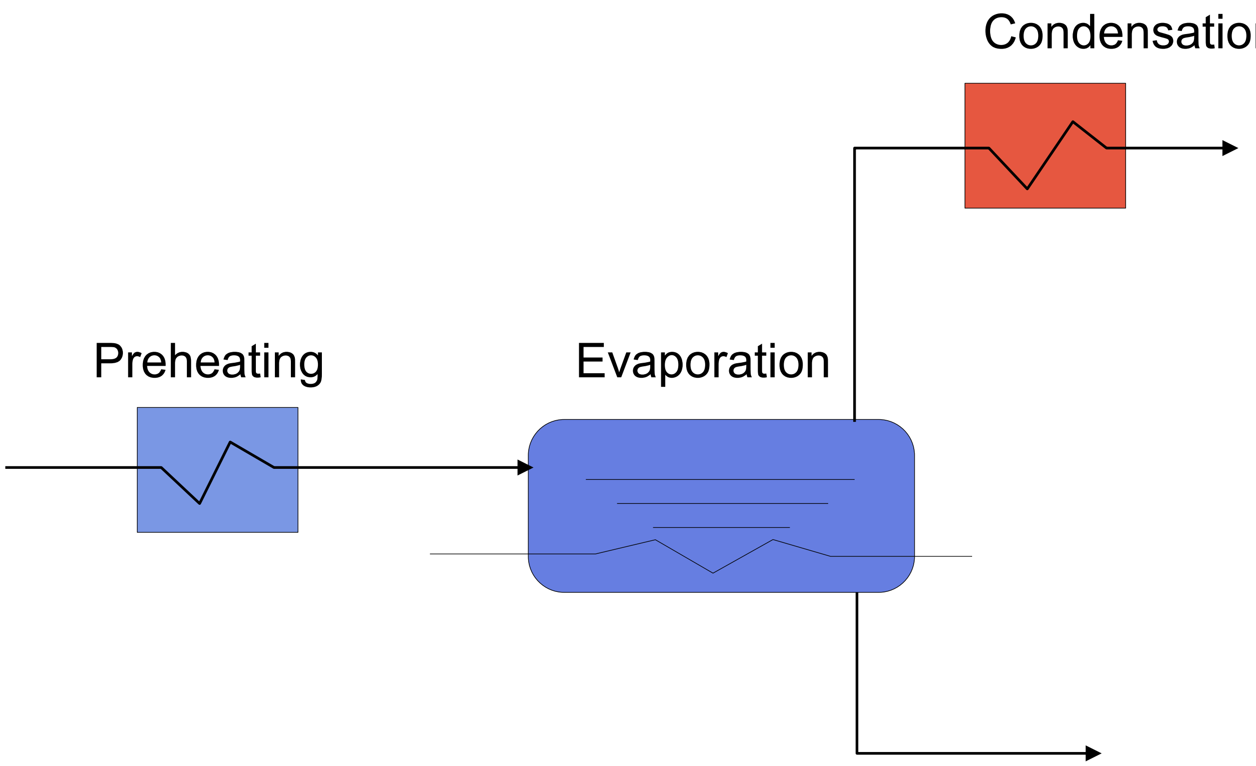


From the actual model of evaporators…



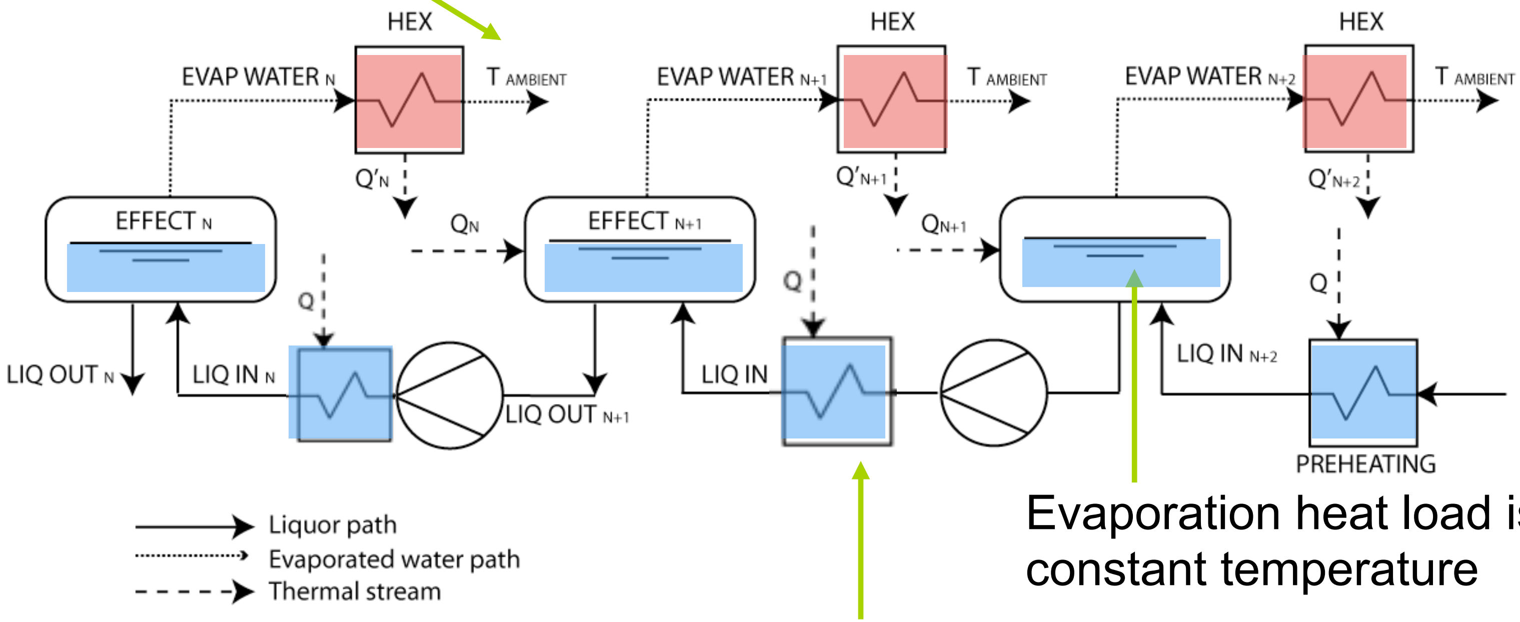
Single effect modeling

- Understanding the unit operation



…to the simplified model of evaporators

The evaporated water leaving each effect is cooled down to ambient temperature → Amount of heat recovered

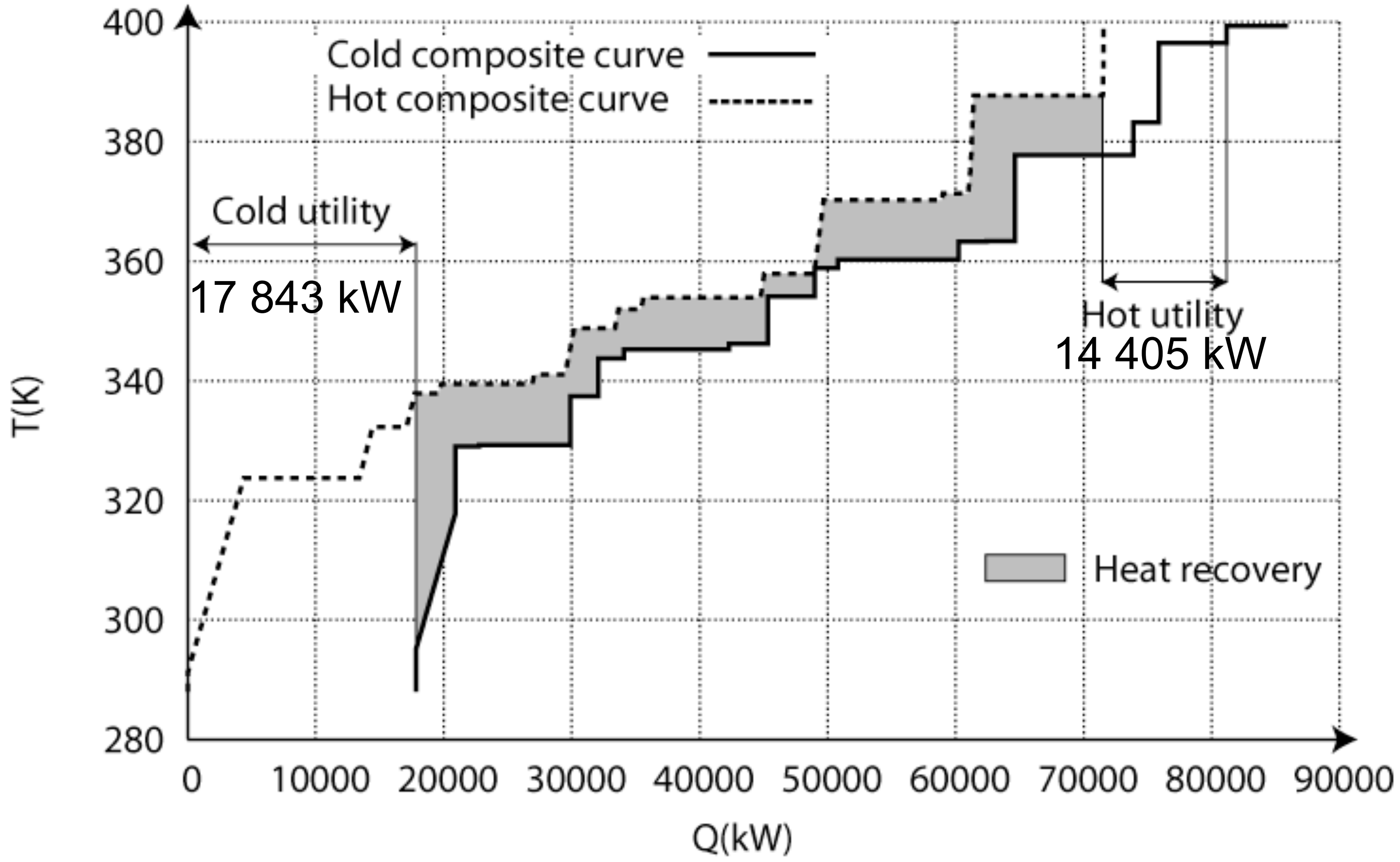


Evaporation heat load is at constant temperature

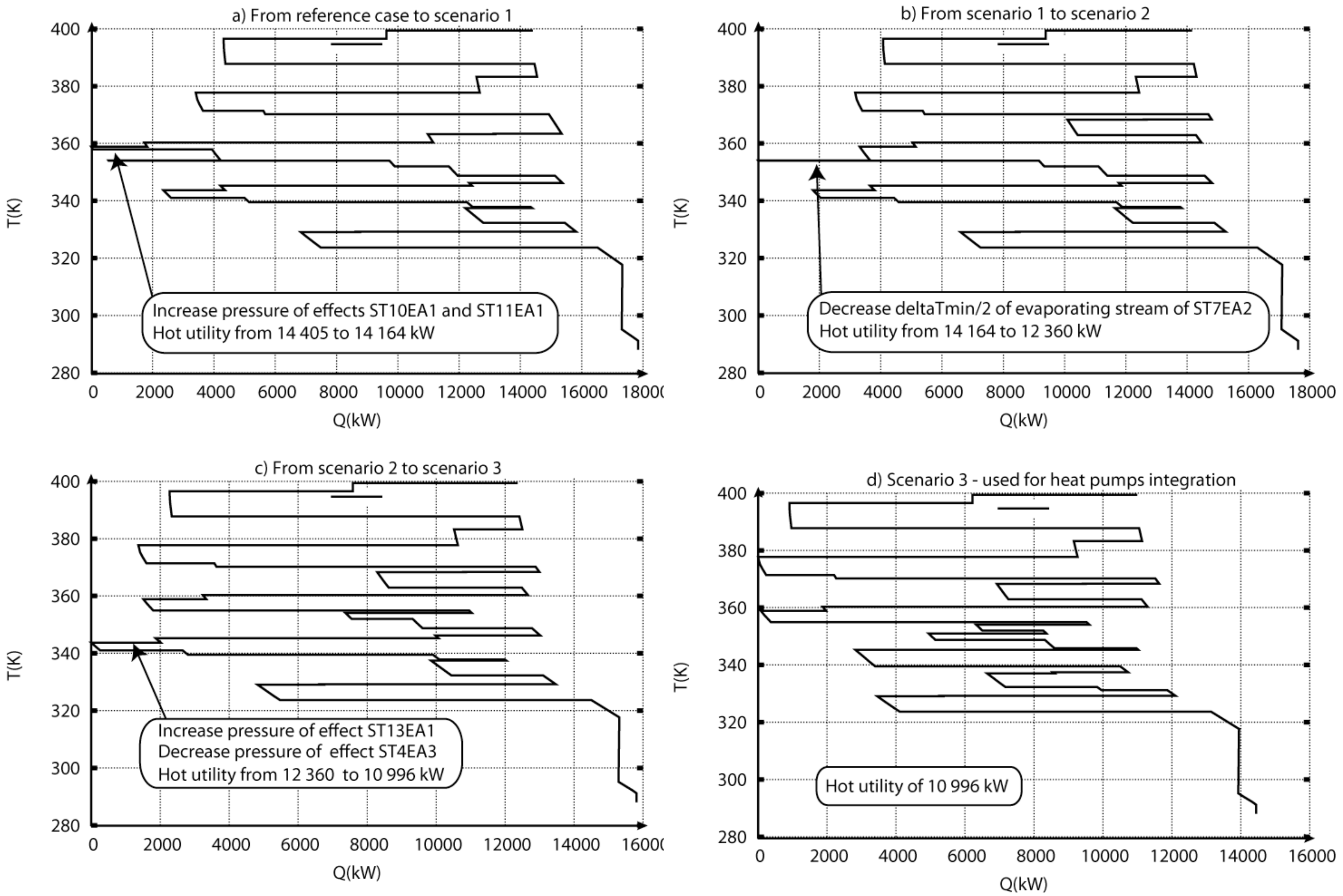
Preheating is possible between effects

Actual process requirement

- Multi-effect system for one concentration



Applying plus-minus principles



Note that the effect is limited by the activation of an other pinch point

Comparison of energy saving scenarios

	Scenario 0	Scenario 1	Scenario 2	Scenario 3
Pinch point (corr temp) (K)	359	354	344	378
Hot utility requirement (kW)	14 405	14 164	12 360	10 996
Cold utility requirement (kW)	17 843	17 616	15 813	14 447
Hot utility cost (k€ /y)	1245	1224	1068	950
Cold utility cost (k€ /y)	154	152	137	125
Cost total utilities (k€ /y)	1399	1376	1205	1075
Total HEX area (m^2)	3875	4058	5286	6176
NminMER	16	16	16	16
HEX area (m^2)	242	254	330	386
Cost total HEX area (k€)	603	633	749	763
Cost total HEX area/y (k€ /y)	70.43	73.95	87.55	88.99

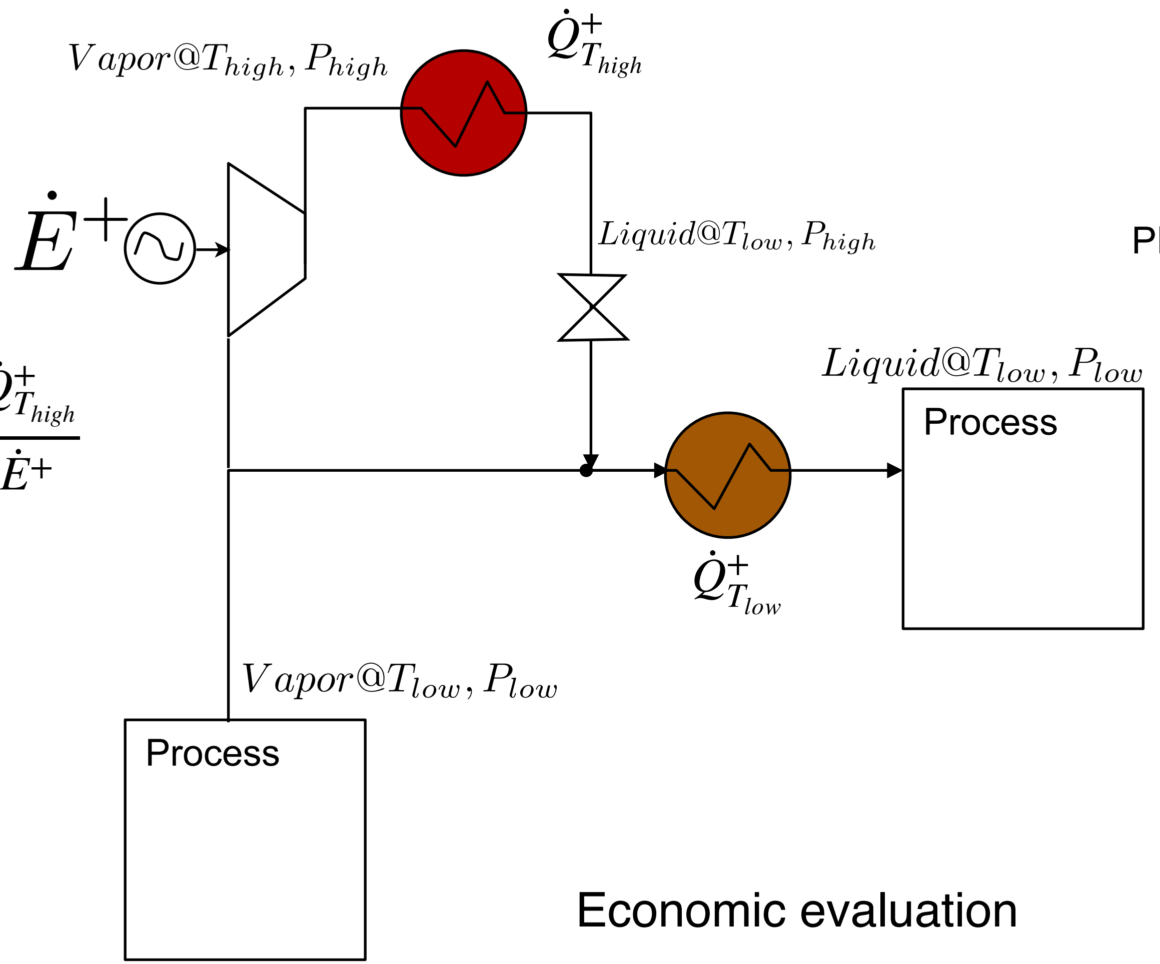
Comparison of energy saving scenarios

	Scenario 0	Scenario 1	Scenario 2	Scenario 3
Comparison with the reference case				
Utility demand (%)	-	-1.5	-12.6	-21.1
Cost total utilities (%)	-	-1.6	-13.9	-23.2
Total HEX area (%)	-	+4.7	+36.4	+59.4
Cost total HEX area year (%)	-	+5.0	+24.3	+26.4

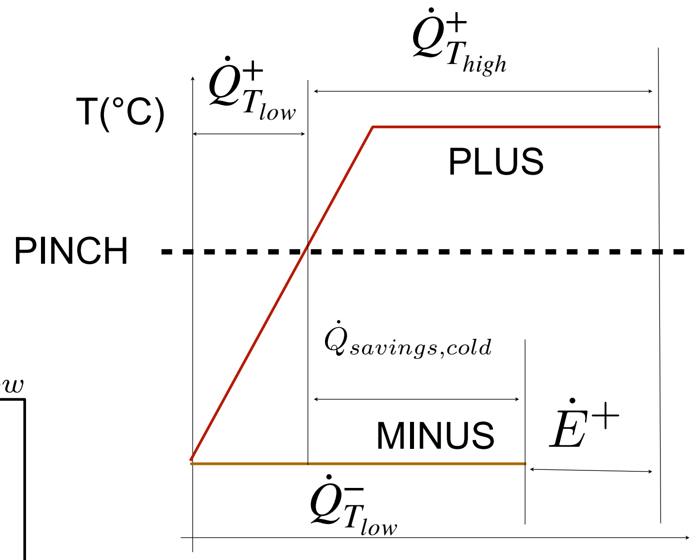
As the curves are closer one from the other, the heat recovery area and the associated investment cost is going to increase

Changing operating conditions : Mechanical Vapour Recompression

- From below the pinch to above the pinch



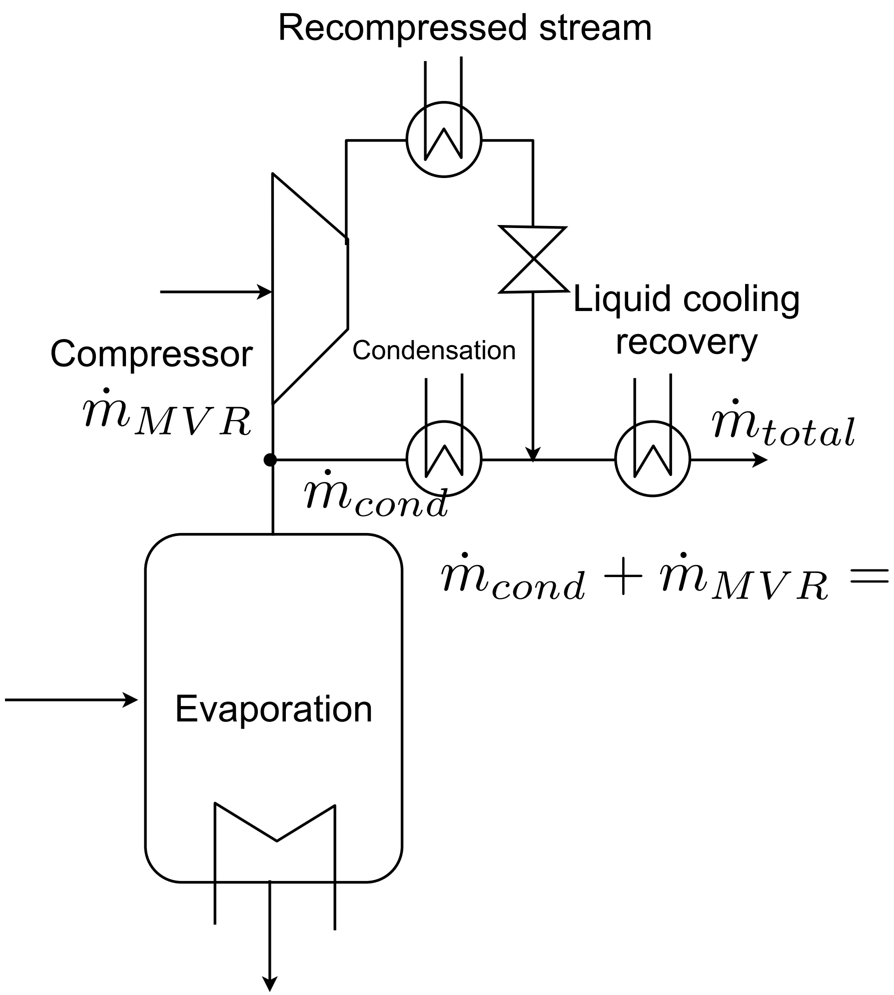
$$COP = \frac{\dot{Q}^+_{T_{high}}}{\dot{E}^+}$$



Economic evaluation

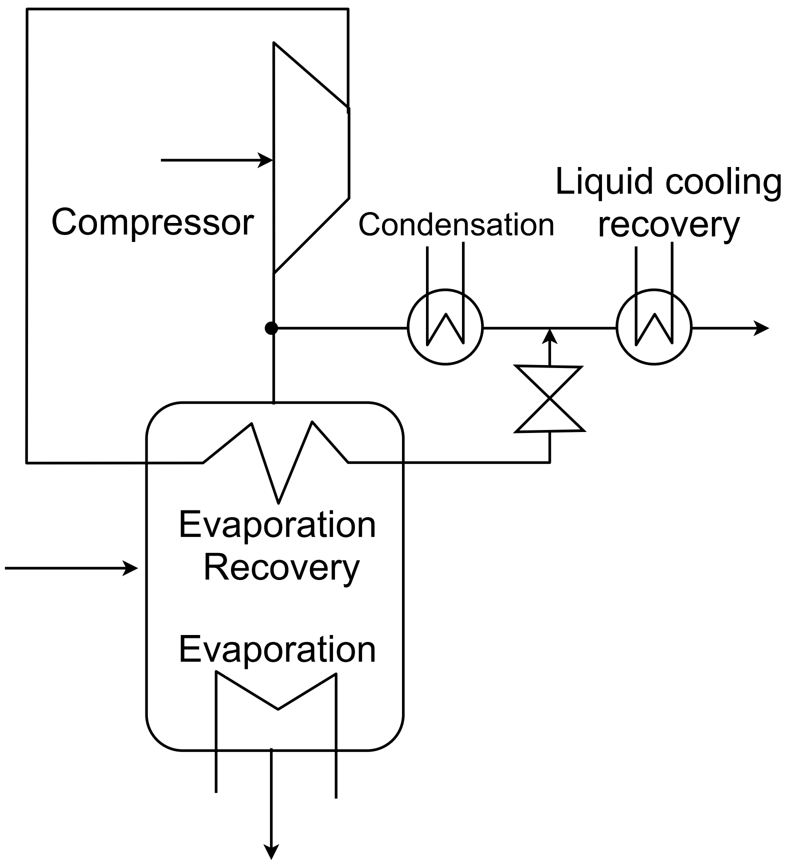
$$(\dot{Q}^+_{T_{high}} \, . \, v^+_{hot} + (\dot{Q}^+_{T_{high}} - \dot{Q}^+_{T_{low}}) \, . \, v^+_{cold} - \dot{E} \, . \, v^+_{el}) \, . \, t_{op} - \frac{1}{\tau} I_{rmv}(\frac{\dot{Q}^+_{T_{high}}}{U_h \Delta T_h}, \dot{E}, (\frac{\dot{Q}^+_{T_{low}}}{U_{low} \Delta T_{low}}))$$

Correct integration : Partial flows are possible



$$\dot{m}_{cond} + \dot{m}_{MVR} = \dot{m}_{total}$$

Process requirements

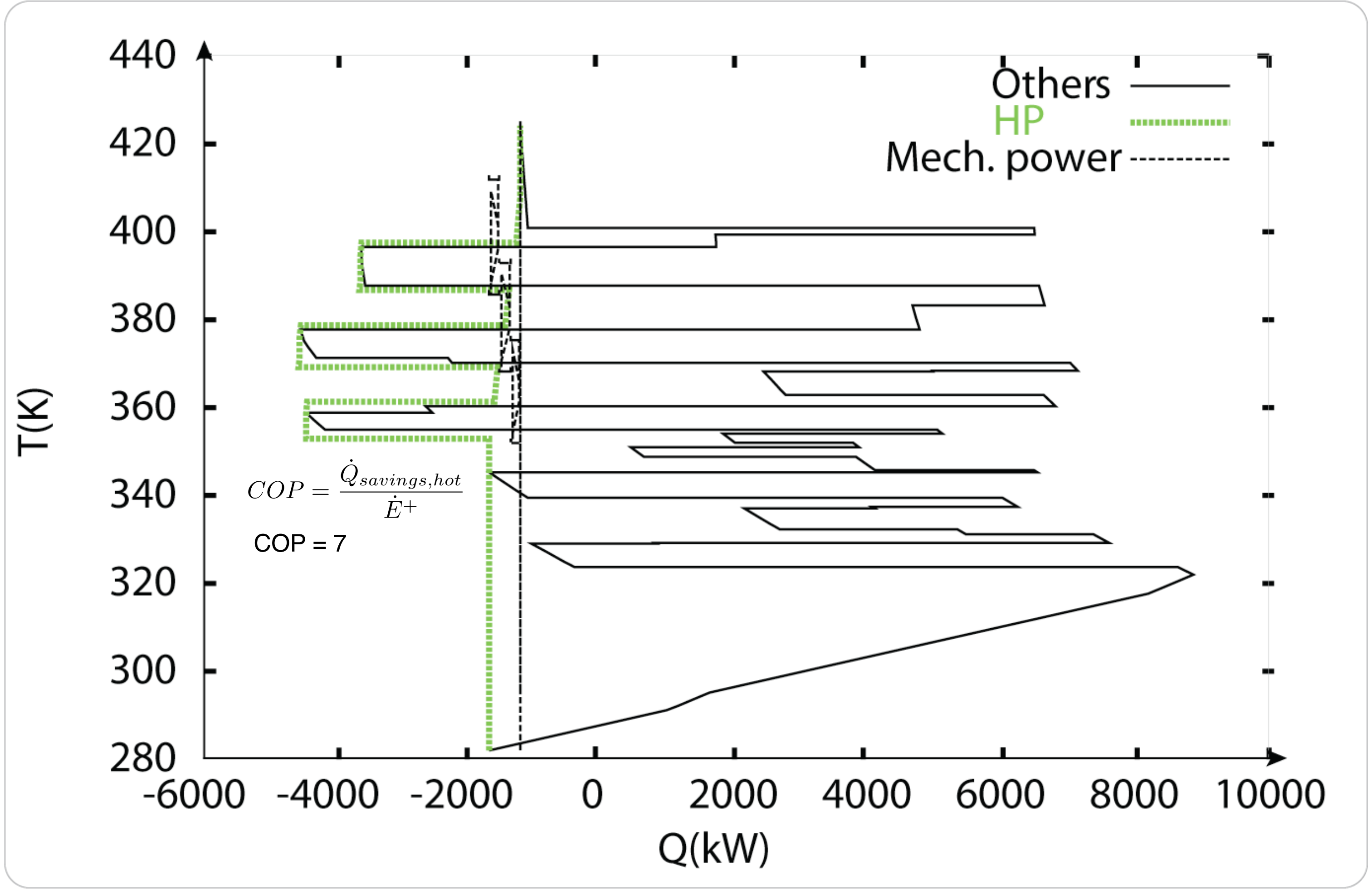


In practice

if only part of the heat load is useful, then it is always possible to compress only part of the flow in order to reduce the compression power

Multiple heat pumps integration

- Multi -effect evaporator case



Energy saving options

Operating, investment and total costs and savings for heat pump integration scenario

	OC* (k€/y)	ΔOC (k€/y)	IC (k€)	ΔIC (k€)	ΔIC/y (k€/y)	TC (k€/y)	Savings (k€/y)	Savings (%)
1 Original scenario	2807	0	4452	0	0	2807	0	0
2 Process improvements	2143	-664	5019	592	69	2212	595	12.2
3 Improved scenario + HP	1647	-1160	7007	2555	376	2023	784	27.2

* OC: operating cost , ΔOC: operating cost reduction, IC: investment cost, ΔIC: investment cost reduction, ΔIC/y: annualized investment cost, TC: total cost

ENERGY SAVING OPTIONS

1. Heat exchange integration
2. Process improvements (decrease ΔTmin and increase/decrease pressures of evaporation effects)
3. Heat pump (HP) integration

- Reduction of the minimum energy requirement by 20%
- Reduction of the utility cost by 23%