The Concept of DTmin

Thermo-economic evaluation of a heat recovery project

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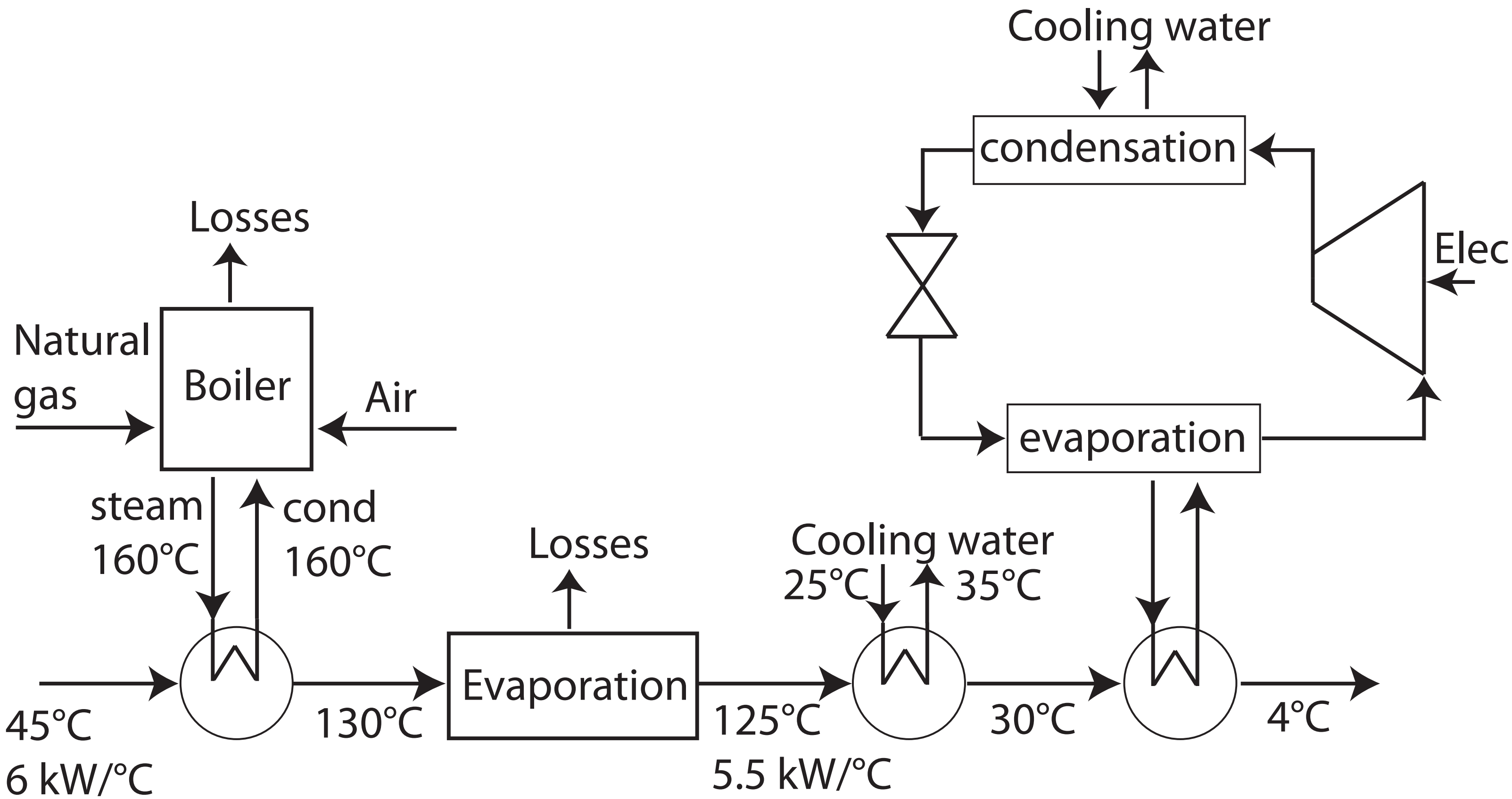
Document thermo-economic evaluation on moodle

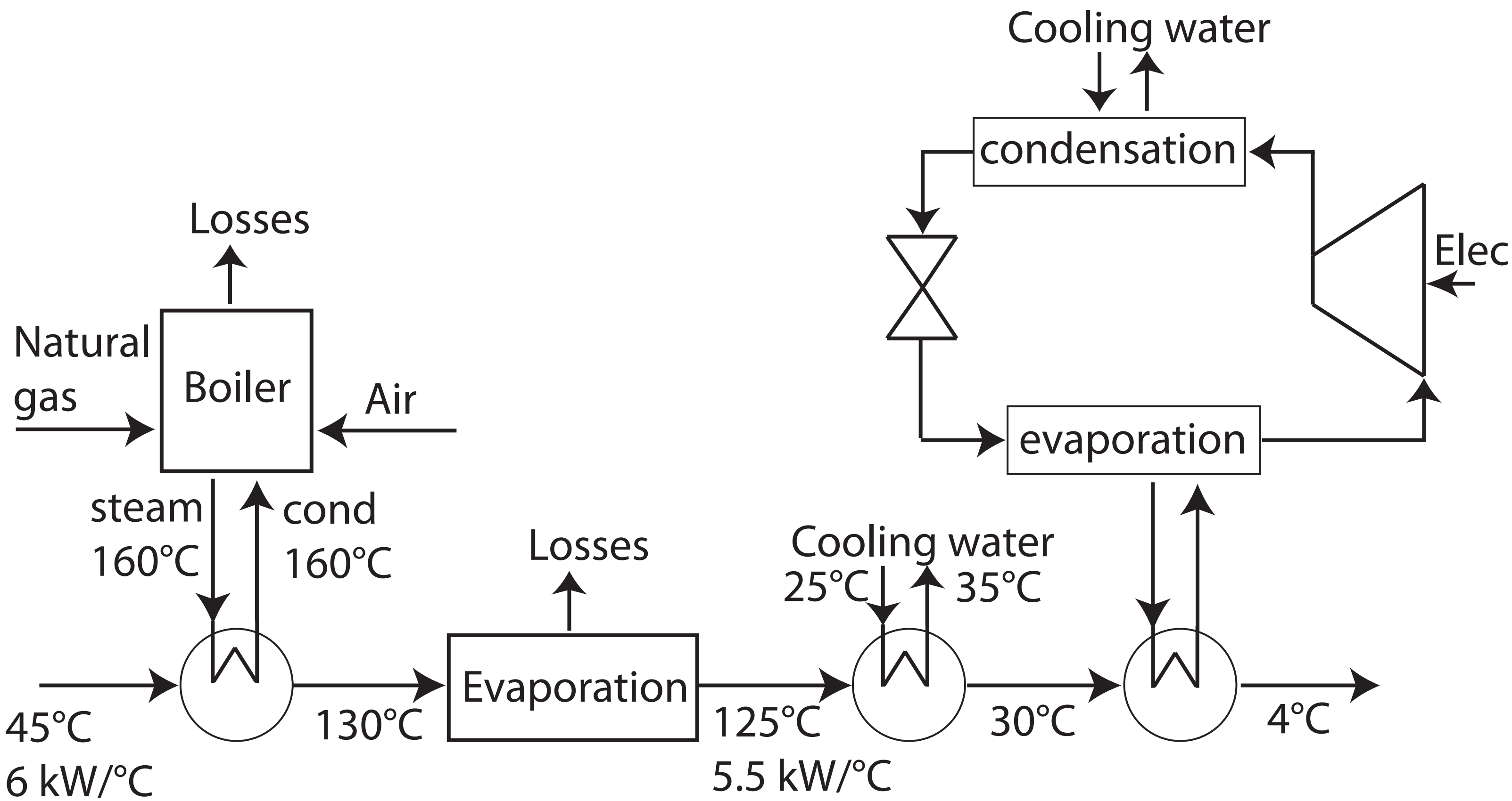
Reduce the energy bill ?



Group work : the A of Agir

- **What are the ways to reduce the energy bill and what is needed to decide**
  - Prepare an ordered list of actions
    - what to calculate ? Phys. units !
    - what is needed ? (Parameters)
    - where to find the information ?
- **10 min for establishing a work plan**
  - Class discussion

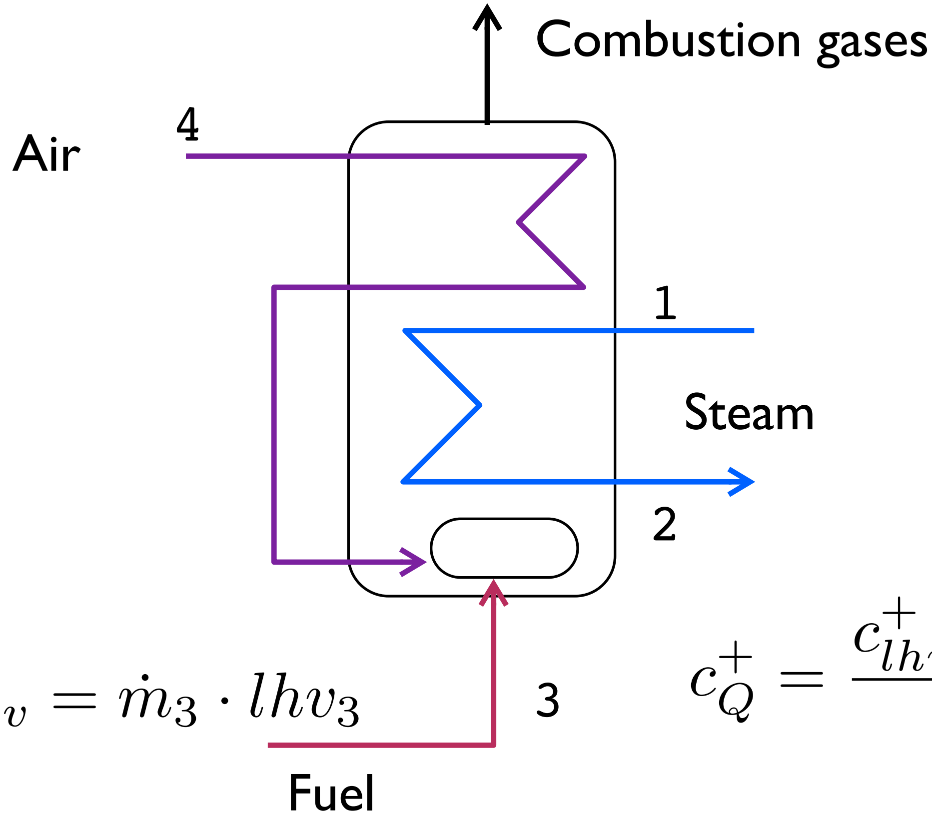
The present situation



Heating

Cooling

Calculating the bill of heat supply (hot utility)



$$\dot{Q} = \dot{m}_1 \cdot (h_1 - h_2)$$

$$\eta = \frac{\dot{Q}}{\dot{m}_3 \cdot lhv_3}$$

$$\dot{E}_{lhv} = \dot{m}_3 \cdot lhv_3$$

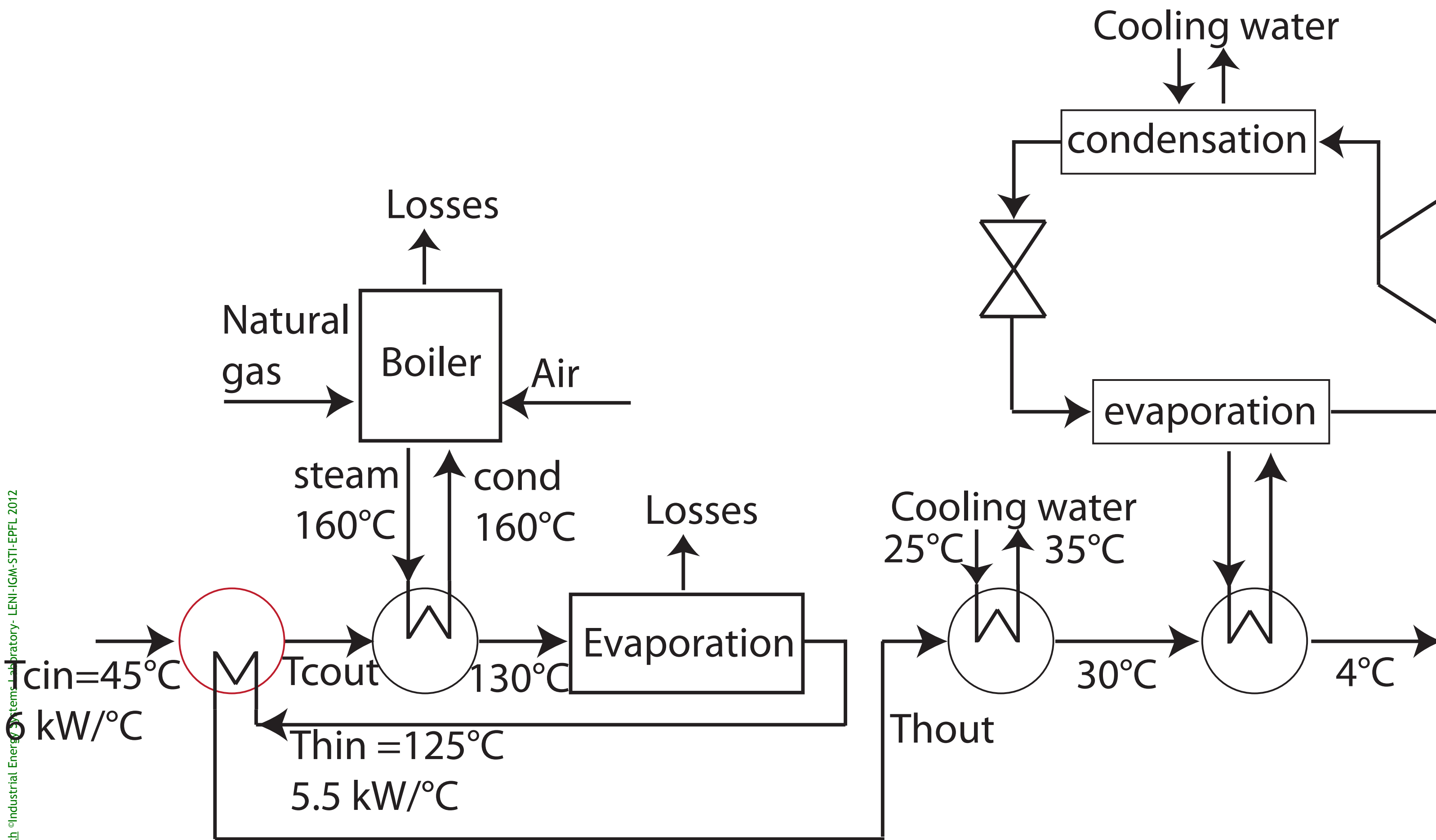
$$c_Q^+ = \frac{c_{lhv}^+ \cdot \dot{m}_3 \cdot lhv_3}{\dot{Q}} \qquad [CHF/kJ]$$

$$C_{fuel} = \int_{t_0}^{t_{year}} (c_{lhv}^+(t) \cdot \dot{m}_3(t) \cdot lhv_3)dt \qquad [CHF/year]$$

Heating bill (constant price of heat):

$$C_{fuel}[CHF/year] = \dot{Q} \cdot c_Q^+ \cdot t_{op}$$

Heat recovery by adding a heat exchanger



A : What is needed

- Process modification
  - New flowsheet : configuration of energy saving
  - Operating conditions
- Operating cost savings [CHF/year] from $\Delta\dot{Q}^+_{ex}$ for the expected life time
  - Expected Cost of energy **for the life time** of the heat exchanger
    - Heat supply: [CHF/kJ$_{heat}$]
    - Cold supply: [CHF/kJ$_{cold}$]
    - Refrigeration supply: [CHF/kJ$_{refrigeration}$]
  - Operating time (t_{op} [s/year]) =>

    $$\Delta\dot{Q}[kW \quad or \quad kJ/s] \cdot c^+_Q[CHF/kJ] \cdot t_{op}[s/year] = Savings \text{ [CHF/year]}$$
- Capital cost expenses [CHF/year]
  - Size of the equipment
  - Investment required [CHF]
  - Annualisation [CHF/year]
    - expected life time
    - Interest rate

A : What is needed

- Capital cost expenses [CHF/year]
  - ➡Size of the equipment
  - – Investment required [CHF]
  - – Annualisation [CHF/year]
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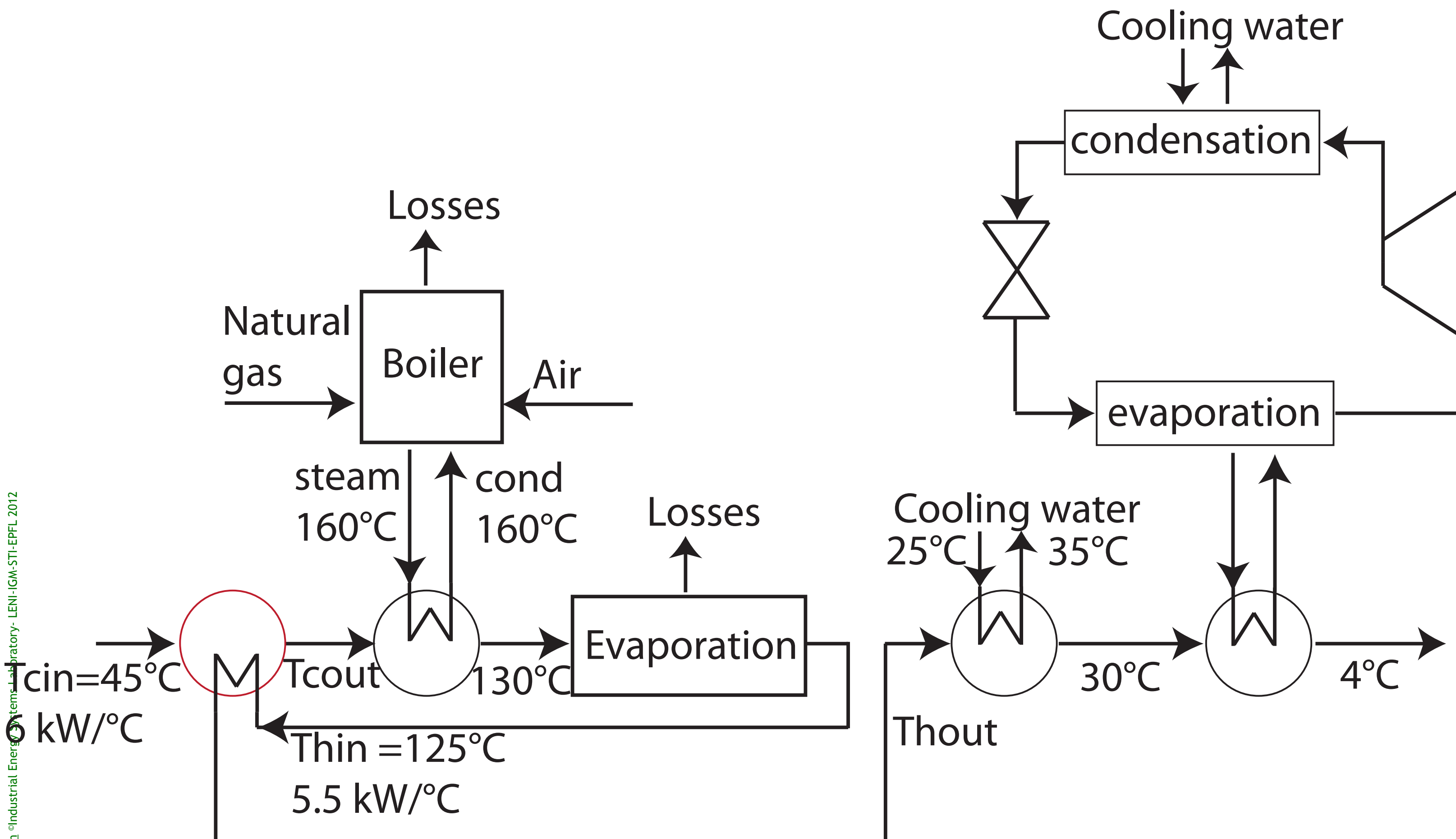
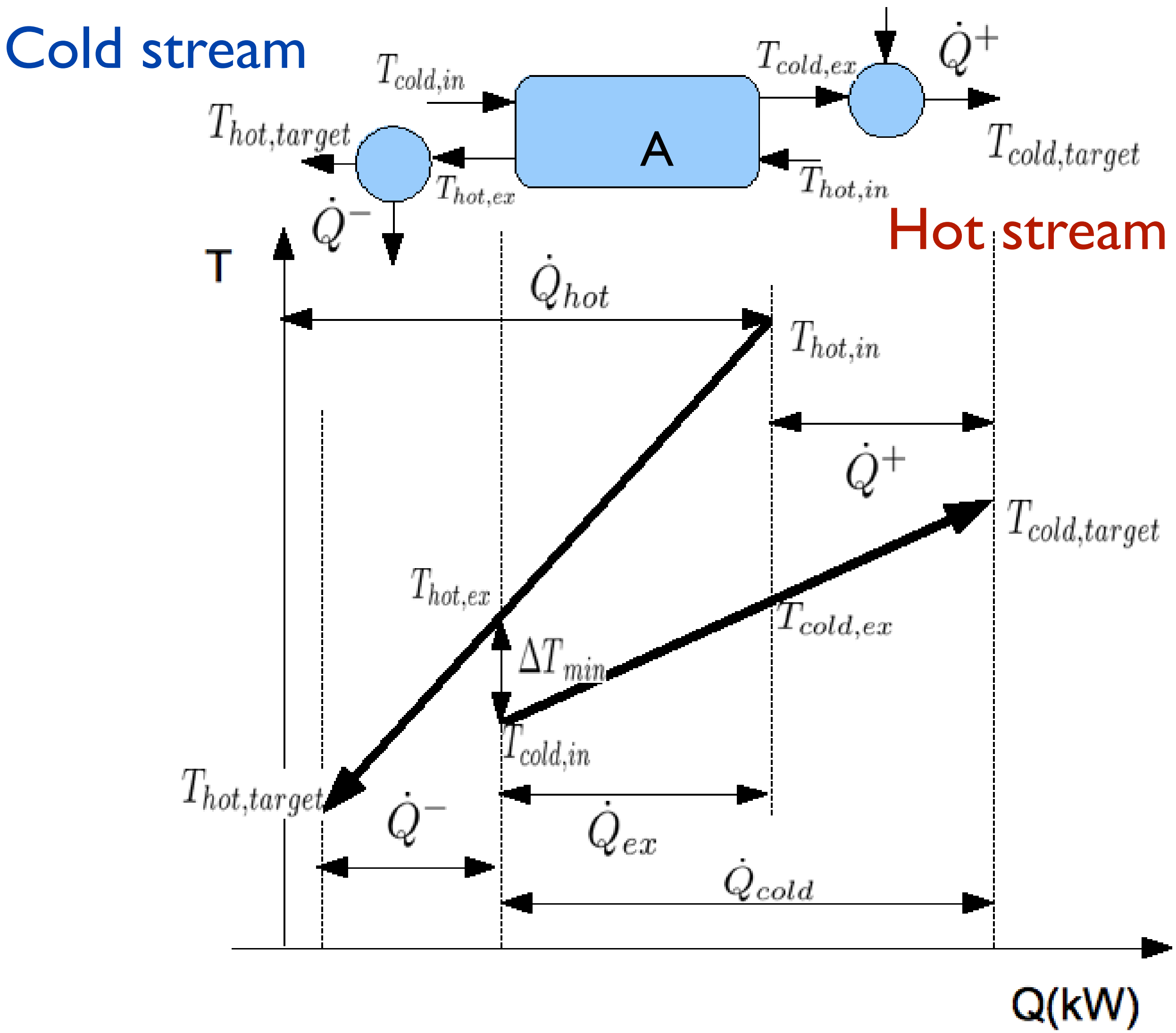
Heat recovery by adding a heat exchanger



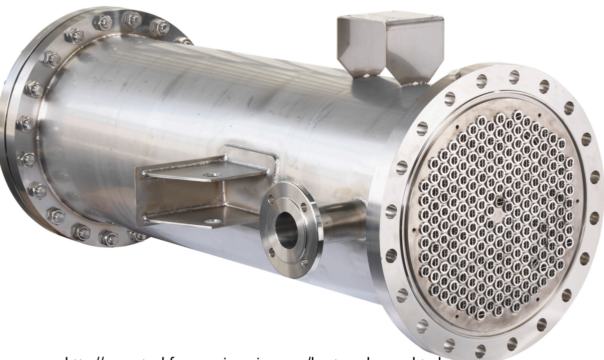
EPFL

Heat recovery : size of the heat exchanger

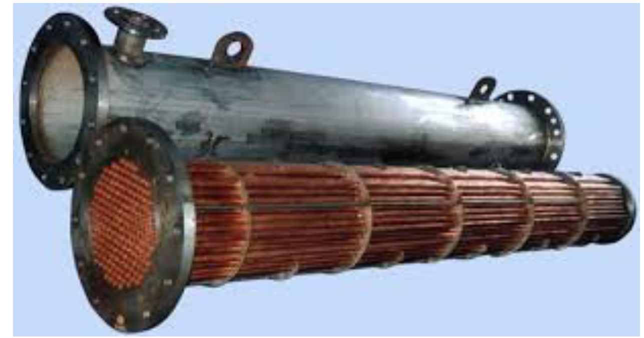


Heat exchangers

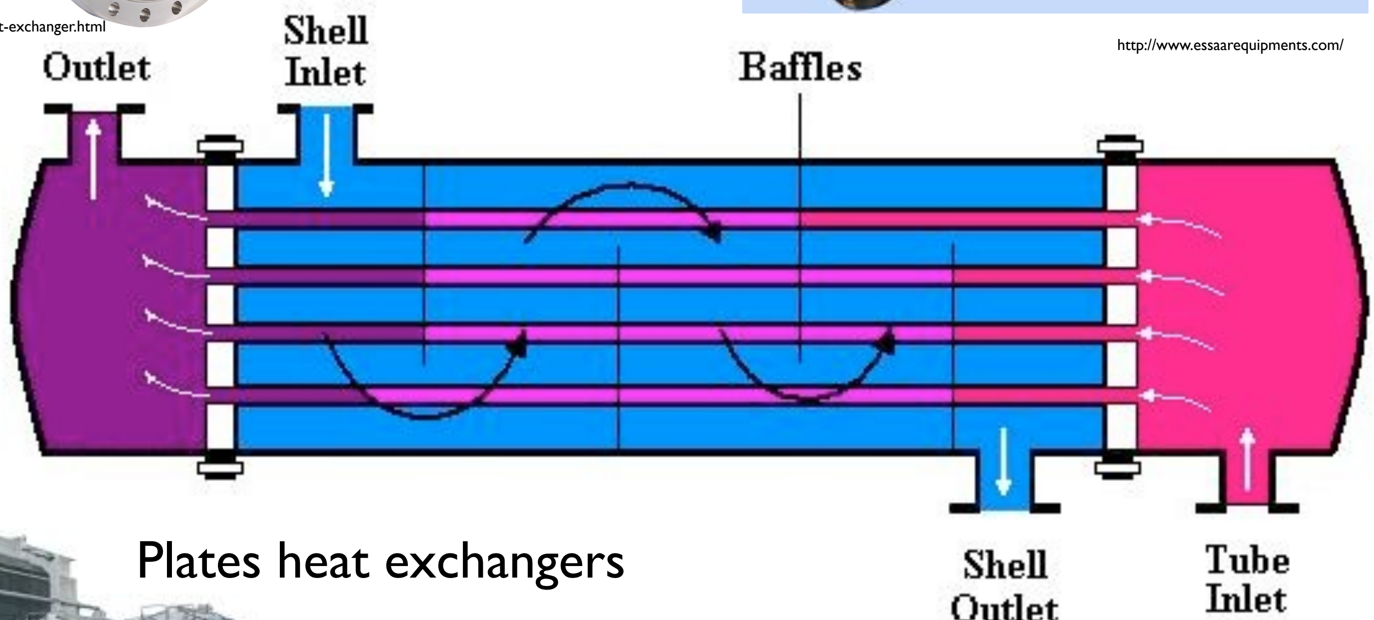
shell and tubes



http://www.techformengineering.com/heat-exchanger.html



http://www.essaarequipments.com/

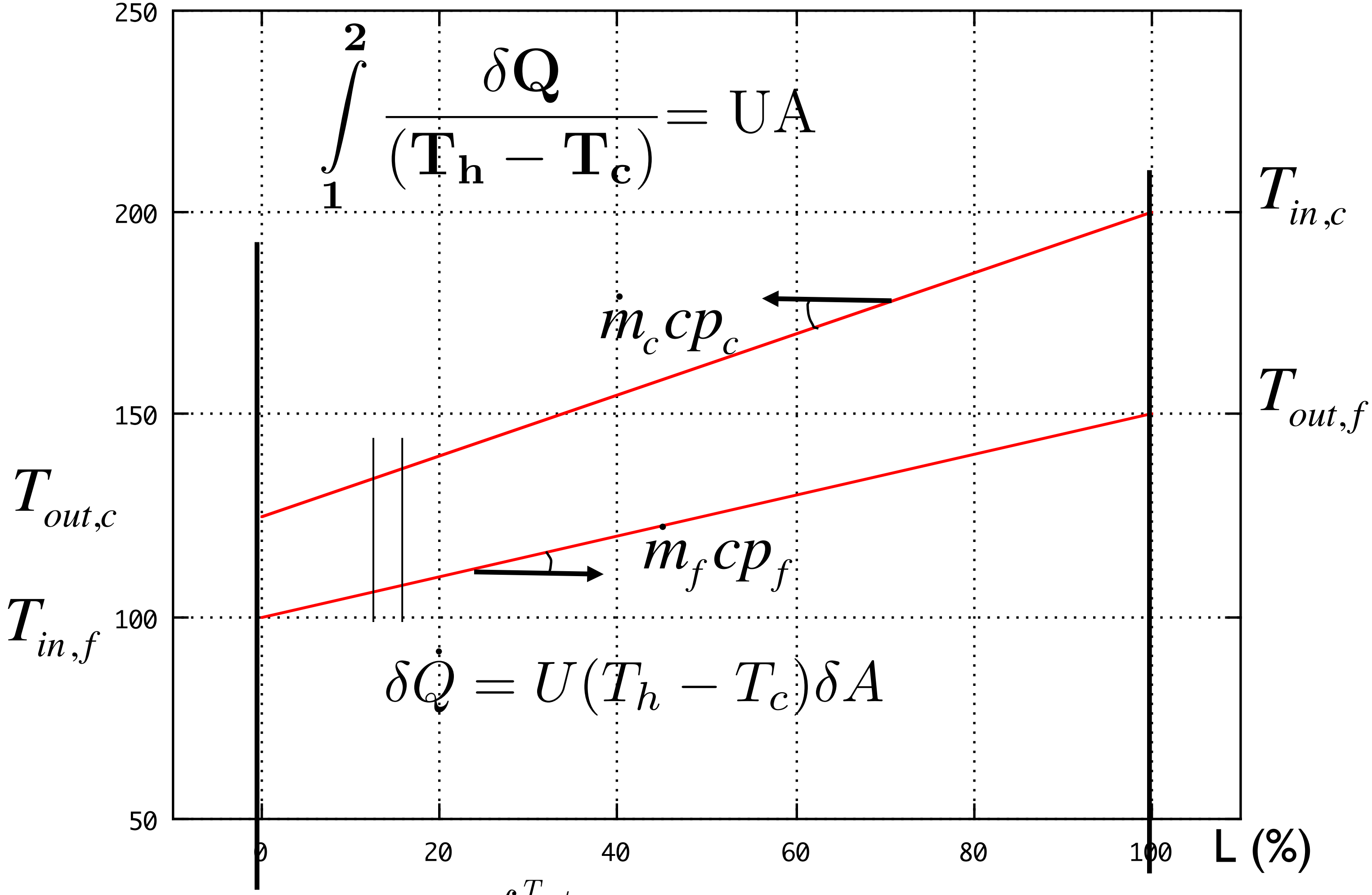


Plates heat exchangers

http://www.arabianoilandgas.com

EPFL

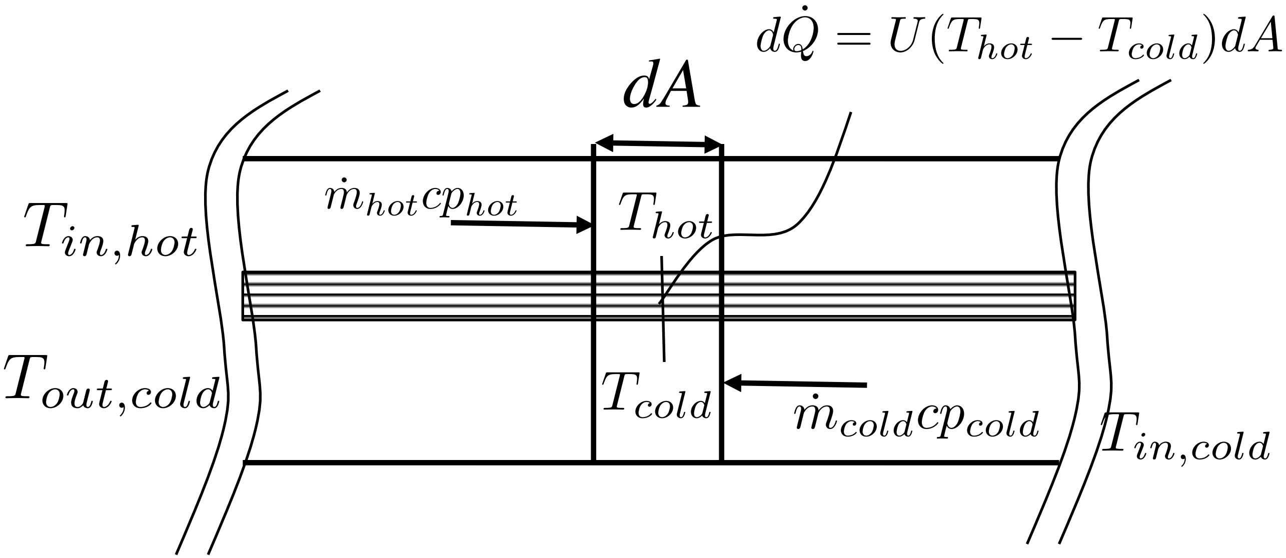
Counter current heat exchanger model

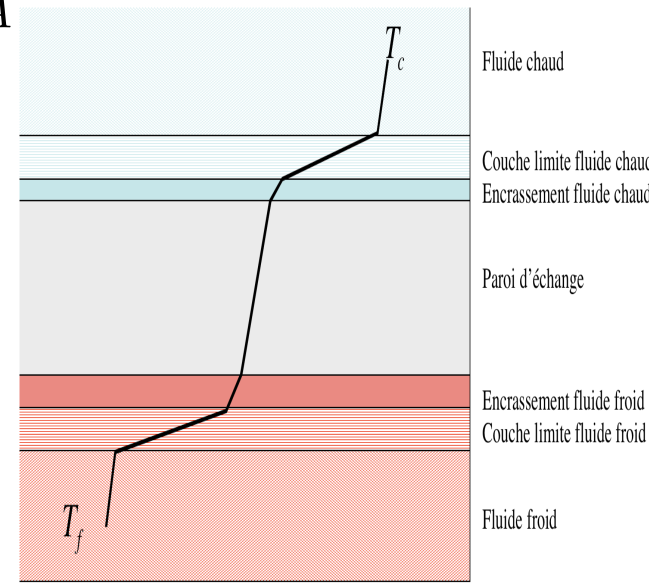


$$\dot{Q} = -\dot{m}_c \int_{T_{in,c}}^{T_{out,c}} cp_c\, dT \simeq \dot{m}_c\, cp_c (T_{in,c} - T_{out,c})$$

$$\dot{Q} = \dot{m}_f \int_{T_{in,f}}^{T_{out,f}} cp_f\, dT \simeq \dot{m}_f\, cp_f (T_{out,f} - T_{in,f})$$

Heat transfer





Fluid heat transfer resistance

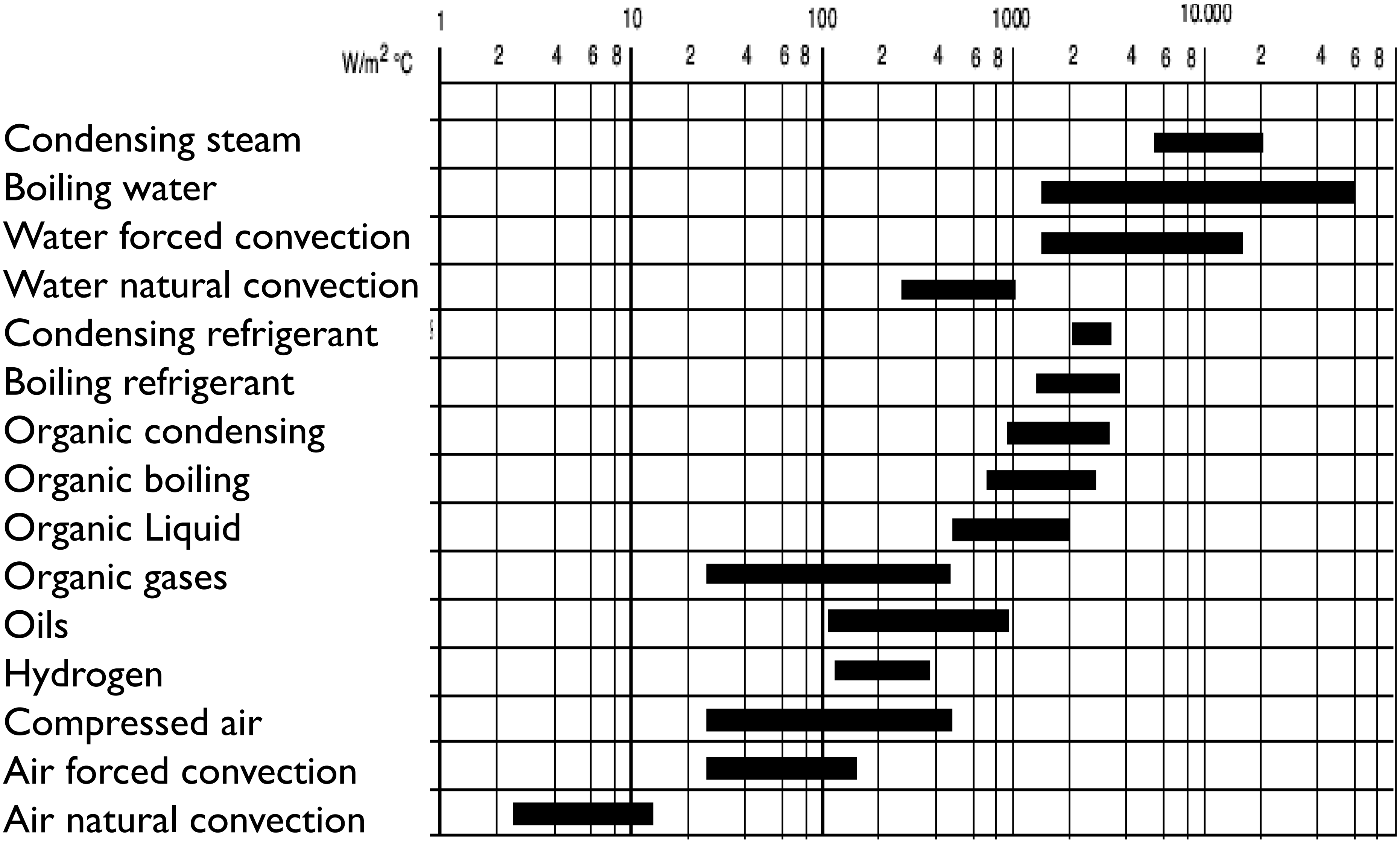
$$\frac{1}{U}\left[\frac{m^2K}{kW}\right] = \frac{1}{\alpha_{hot}} + \frac{e}{\lambda} + \frac{1}{\alpha_{cold}} + R$$

Conductivity
Often deglected

Fouling

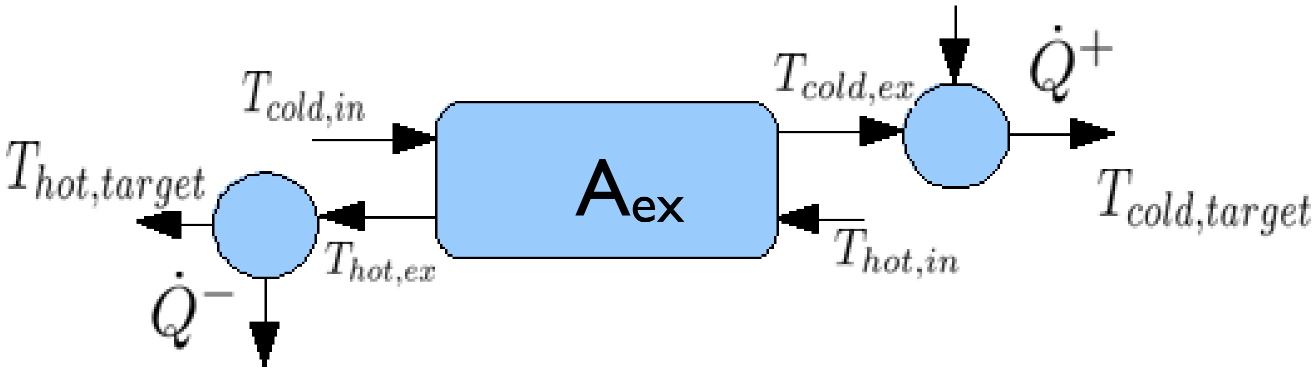
see prof Thome Lectures

Heat transfer coefficient



Heat transfer coefficient table

Sizing by heat exchanger model



$$\int_1^2 \frac{\delta \mathbf{Q}}{(\mathbf{T_h} - \mathbf{T_c})} = \mathrm{UA}$$

$$\dot{Q}_{ex} = \dot{M}_{hot}\, c_{p_{hot}}(T_{hot,in} - T_{hot,ex}) = \dot{M}_{cold}\, c_{p_{cold}}(T_{cold,ex} - T_{cold,in})$$

$$\dot{Q}_{ex} = U_{ex} A_{ex} \Delta T_{lm}$$

$$\Delta T_{lm} = \frac{(T_{hot,in} - T_{cold,ex}) - (T_{hot,ex} - T_{cold,in})}{ln\left(\frac{(T_{hot,in} - T_{cold,ex})}{(T_{hot,ex} - T_{cold,in})}\right)}$$

If cp is constant

$$\frac{1}{U_{ex}} = \frac{1}{\alpha_{cold}} + \frac{e}{\lambda} + \frac{1}{\alpha_{hot}}$$

$$A_{ex} = \frac{\dot{Q}_{ex}}{U_{ex} \Delta T_{lm}}$$

With:

U_{ex}	$[kW/m^2/K]$	the global heat transfer coefficient of the heat exchanger;
α_{cold}	$[kW/m^2/K]$	the film heat transfer coefficient of the cold stream;
α_{hot}	$[kW/m^2/K]$	the film heat transfer coefficient of the hot stream;
λ	$[kW/m/K]$	the thermal conductivity of the tubes;
e	[m]	the thickness of the tubes.

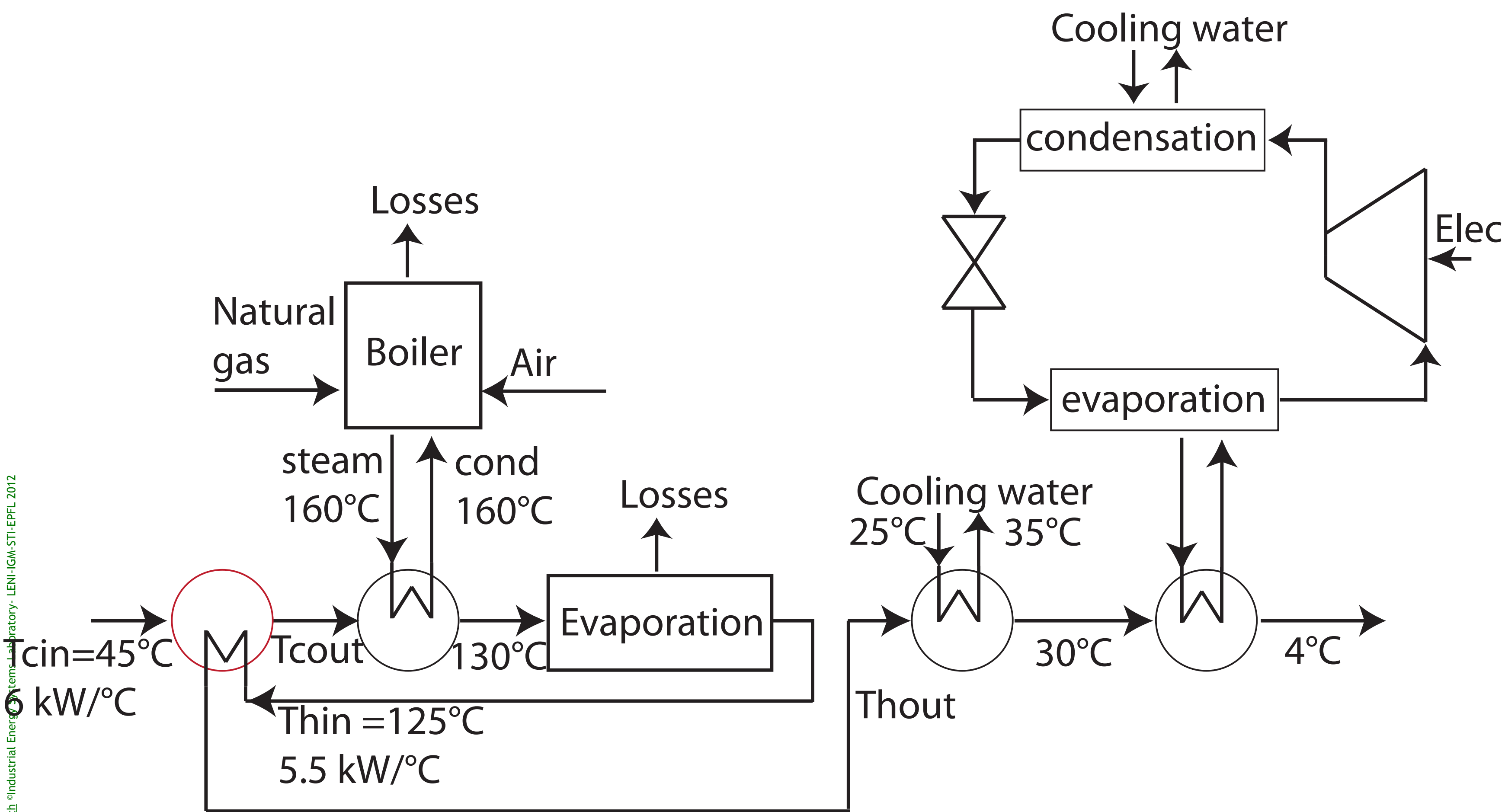
Estimating the investment

- Capital cost expenses [CHF/year]
  - ✓Size of the equipment
  - ➡Investment required [CHF]
  - – Annualisation [CHF/year]
    - expected life time
    - Interest rate

Calculating the best size of the heat exchanger

What is the best value of the DTmin
In a heat recovery project

Heat recovery by adding a heat exchanger



IPESE INDUSTRIAL PROCESS AND

EPFL

Project evaluation

- Project evaluation
  - Buying a new heat exchanger

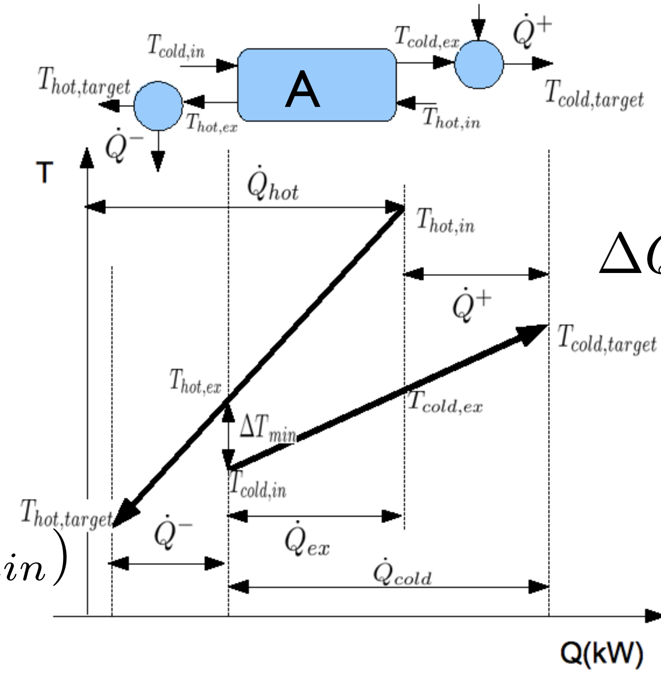
$$CAPEX[CHF/year] = \frac{I}{I_{ref}} k_1 (A)^{k_2} \frac{i(1+i)^n}{(1+i)^n - 1}$$

  - Energy savings
    - Operating cost reduction (OPEX)

$$\Delta OPEX = \int_{years} \dot{m}^0_{energy}(t) c_{energy}(t) dt - \int_{years} \dot{m}^{new}_{energy}(t) c_{energy}(t) dt$$

  - Profitability
    - Compare ΔOPEX(+) and CAPEX(-)

Energy savings values



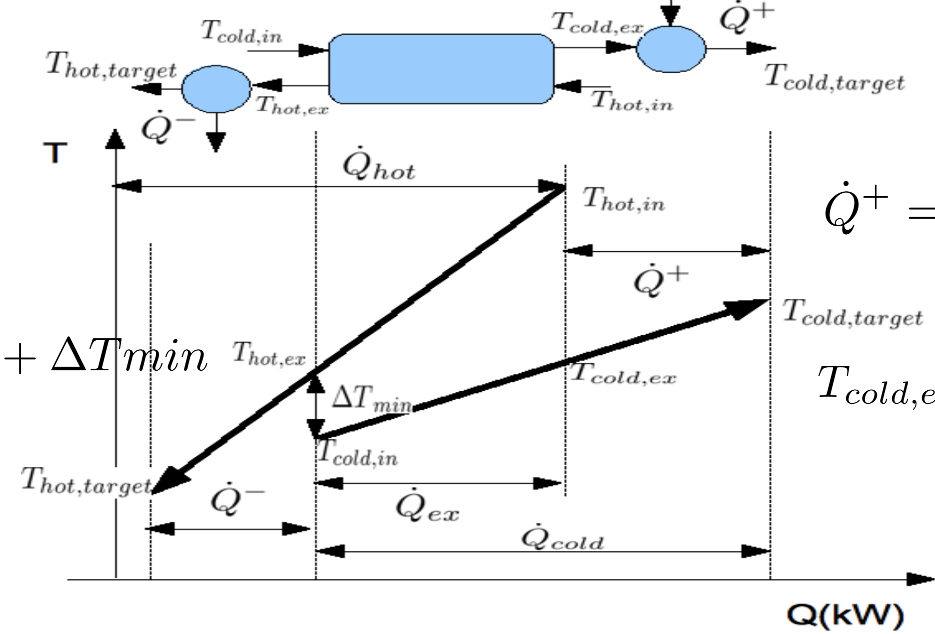
$$\Delta\dot{Q}^+ = \dot{Q}_{ex}(\Delta T_{min})$$

$$\Delta\dot{Q}^- = \dot{Q}_{ex}(\Delta T_{min})$$

$$\Delta OPEX_{ex}(\Delta T_{min}) = (c_{cold} \cdot \dot{Q}_{ex}(\Delta T_{min}) + c_{hot} \cdot \dot{Q}_{ex}(\Delta T_{min})) \cdot time_{year}$$

Heat exchanger size for a given ΔT_{min}

2 $\dot{Q}_{ex}(\Delta Tmin) = \dot{M}_{hot}cp_{hot}(T_{hot,in} - (T_{cold,in} + \Delta Tmin))$



1 $T_{hot,ex} = T_{cold,in} + \Delta Tmin$

5 $\dot{Q}^+ = (\dot{Q}_{cold} - \dot{Q}_{ex}(\Delta T_{min}))$

3 $T_{cold,ex} = T_{cold,in} + \dfrac{\dot{Q}_{ex}}{\dot{M}_{cold}cp_{cold}}$

4 $A_{ex} = \dfrac{\dot{Q}_{ex}}{U_{ex}\Delta T_{lm}}$

6 $\dot{Q}^- = (\dot{Q}_{hot} - \dot{Q}_{ex}(\Delta T_{min}))$

The calculation is made using a sequence of of resolution that is established for a given ΔT_{min}

ΔTmin value : optimization problem

Decision variable

$$min_{\Delta T_{min}} TotalCost = OC_{ex}(\Delta T_{min}) + IC_{ex}(\Delta T_{min})$$

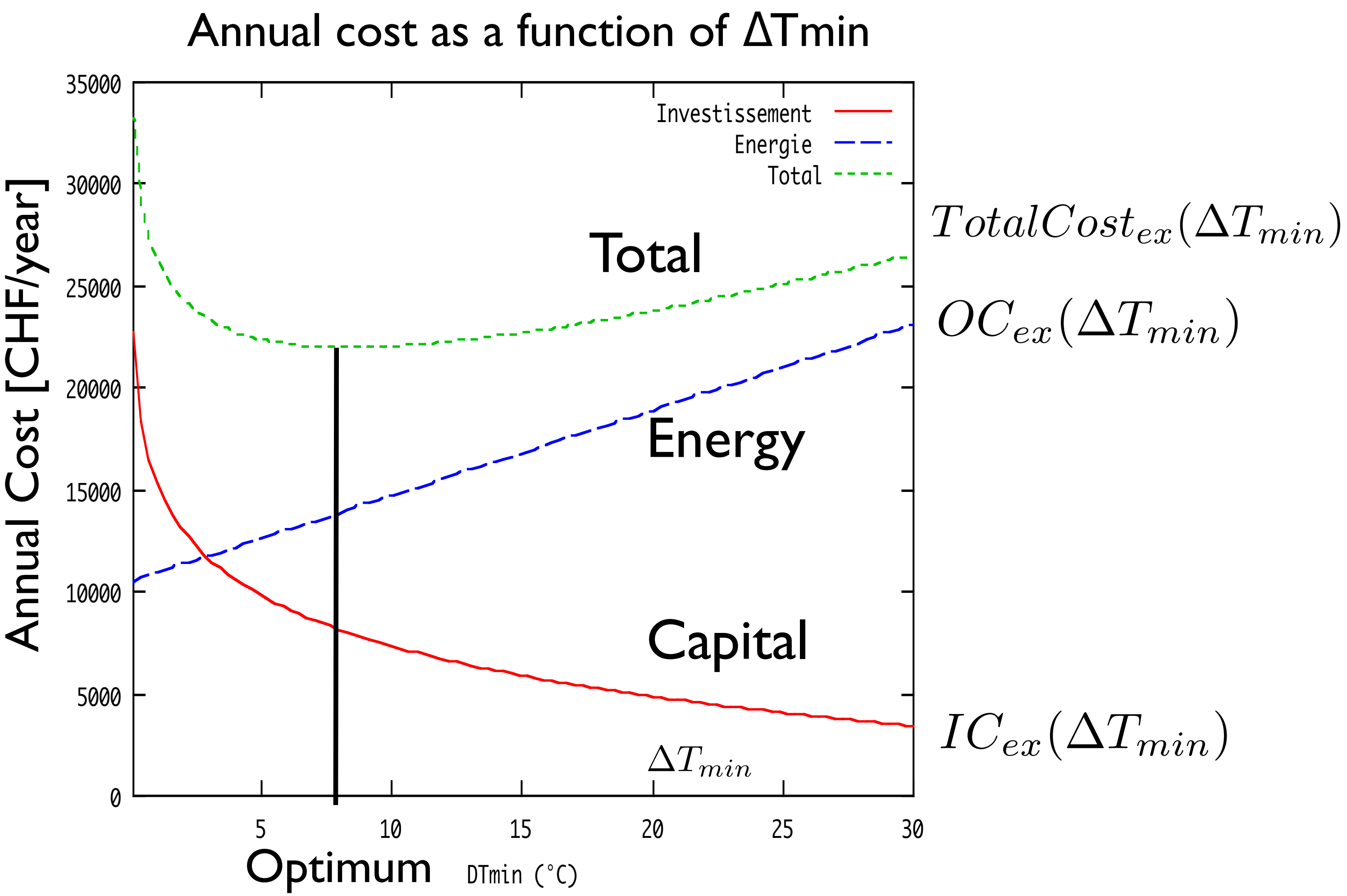
Objective function

$$OC_{ex}(\Delta T_{min}) = (c_{cold} \cdot (\dot{Q}_{hot} - \dot{Q}_{ex}(\Delta T_{min})) + c_{hot} \cdot (\dot{Q}_{cold} - \dot{Q}_{ex}(\Delta T_{min}))) \cdot time_{year}$$

$$OC_{ex}(\Delta T_{min}) = \left((c_{cold} \cdot \dot{Q}_{hot} + c_{hot} \cdot \dot{Q}_{cold}) - \dot{Q}_{ex}(\Delta T_{min}) \cdot (c_{cold} + c_{hot})\right) \cdot time_{year}$$

$$IC_{ex}(\Delta T_{min}) = (\frac{i(1+i)^{ny_{ex}}}{(1+i)^{ny_{ex}} - 1}) a_{ex} (A_{ex}(\Delta T_{min}))^{b_{ex}}$$

ΔTmin value : optimization problem



$$\Delta OC_{ex}(\Delta T_{min}) = \Delta IC_{ex}(\Delta T_{min})$$

ΔTmin value : optimization problem

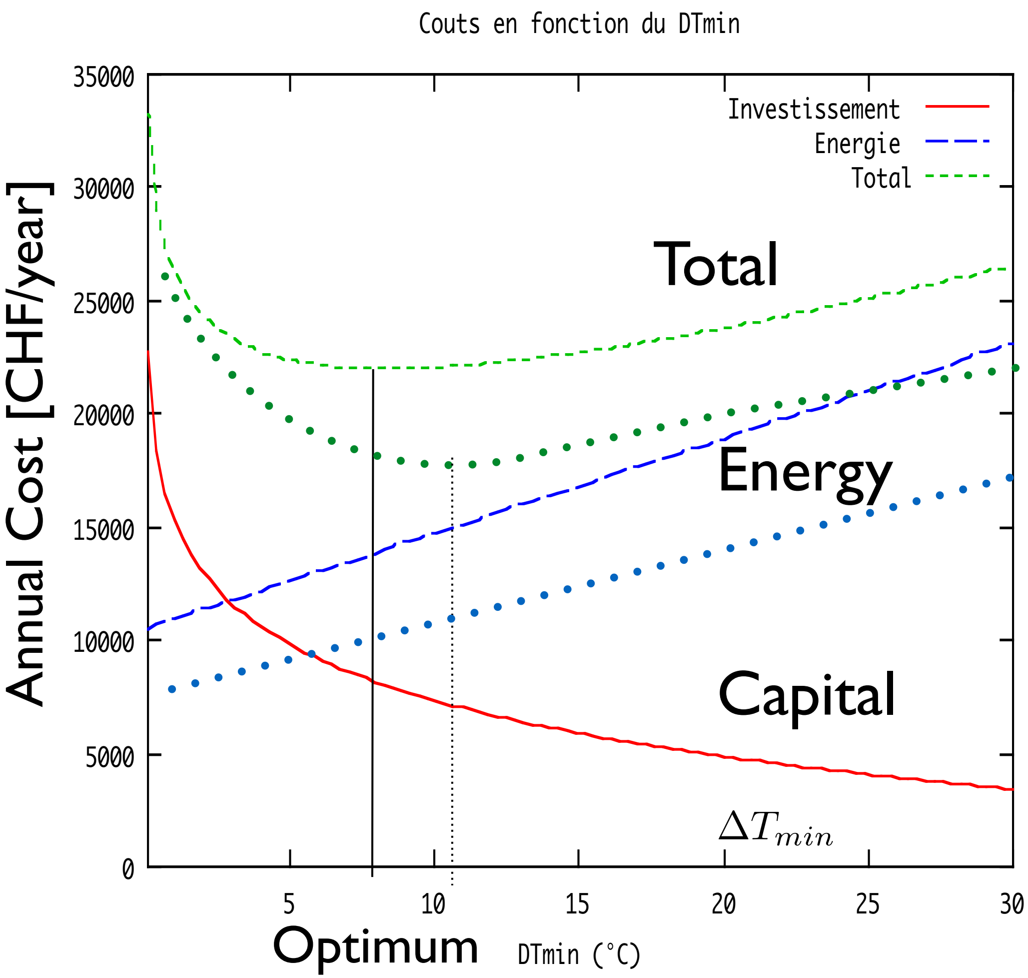
$$min_{\Delta T_{min}} TotalCost = OC_{ex}(\Delta T_{min}) + IC_{ex}(\Delta T_{min})$$

$$OC_{ex}(\Delta T_{min}) = (c_{cold} \cdot (\dot{Q}_{hot} - \dot{Q}_{ex}(\Delta T_{min})) + c_{hot} \cdot (\dot{Q}_{cold} - \dot{Q}_{ex}(\Delta T_{min}))) \cdot time_{year}$$

$$IC_{ex}(\Delta T_{min}) = (\frac{i(1+i)^{ny_{ex}}}{(1+i)^{ny_{ex}} - 1}) \cdot a_{ex} \cdot (\frac{\dot{Q}_{ex}(\Delta T_{min})}{U_{ex}\Delta T_{lm}(\Delta T_{min})})^{b_{ex}}$$

- **ΔT_{min} value depends on**
  - Operating time
  - Heat transfer coefficient
  - Heat load
  - Energy cost
  - Type of heat exchanger
  - Cost of the heat exchanger
  - Investment strategy
    - interest rate
    - expected life time

ΔTmin value : for cheaper energy cost



$TotalCost_{ex}(\Delta T_{min})$

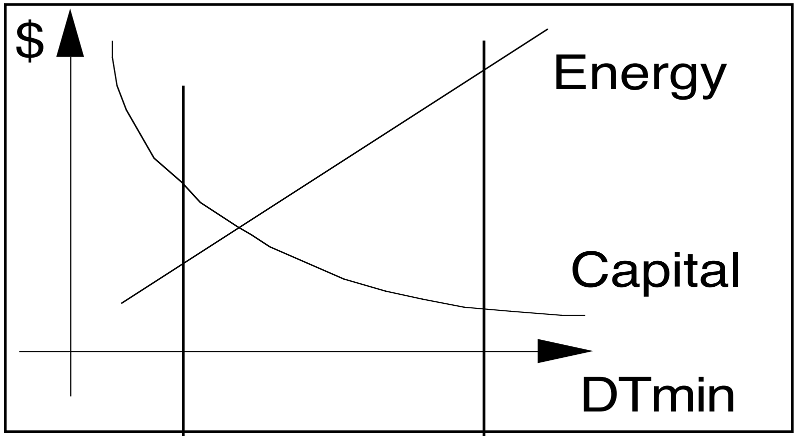
Energy Cost ↘

ΔT_{min} ↗

What is the ΔTmin ?

Minimum approach temperature difference

Energy - Investments Trade-off



Small ΔTmin

- high heat exchange area
  -> high investments
- high heat recovery
  -> small operating costs

Big ΔTmin

- Small heat exchange area
  -> small investments
- Small energy recovery
  -> High operating costs

DT min calculation

- **Defines a temperature difference that makes the heat recovery exchangers profitable for an expected constant energy cost over the lifetime of the heat exchangers**
  - based on the NPV criteria => profitability
  - based on return on investment => risk
  - based on internal rate of return => risk
- **Compare the different criteria**
- **When "optimized"**
  - DTmin means economic feasibility of heat exchanger investment
    - A higher investment would not be compensated by increased energy savings cost
    - A lower investment would lead to lower energy savings cost