
The Concept of DT_{min}

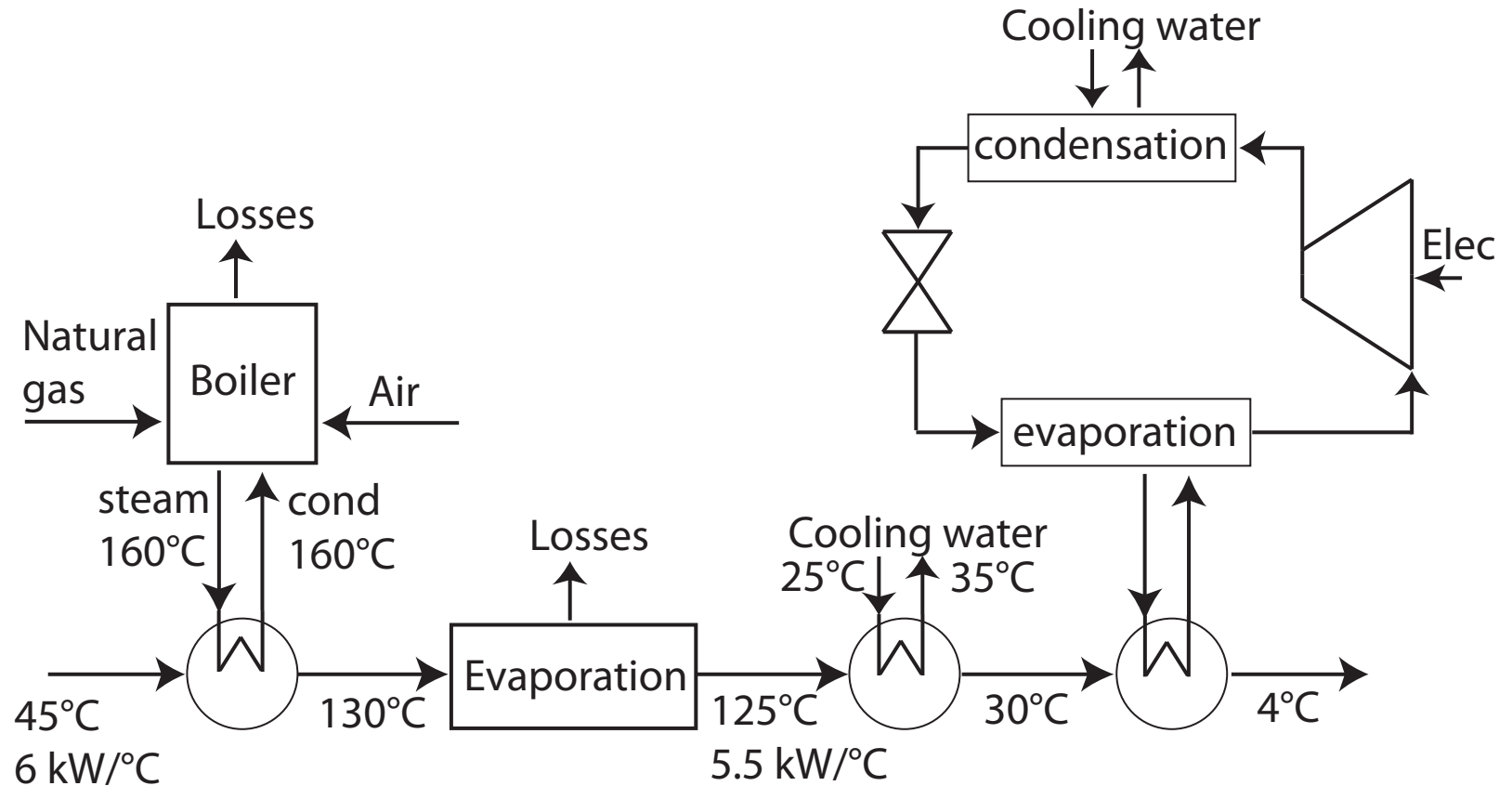
Thermo-economic evaluation of a heat recovery project

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Document thermo-economic evaluation on moodle

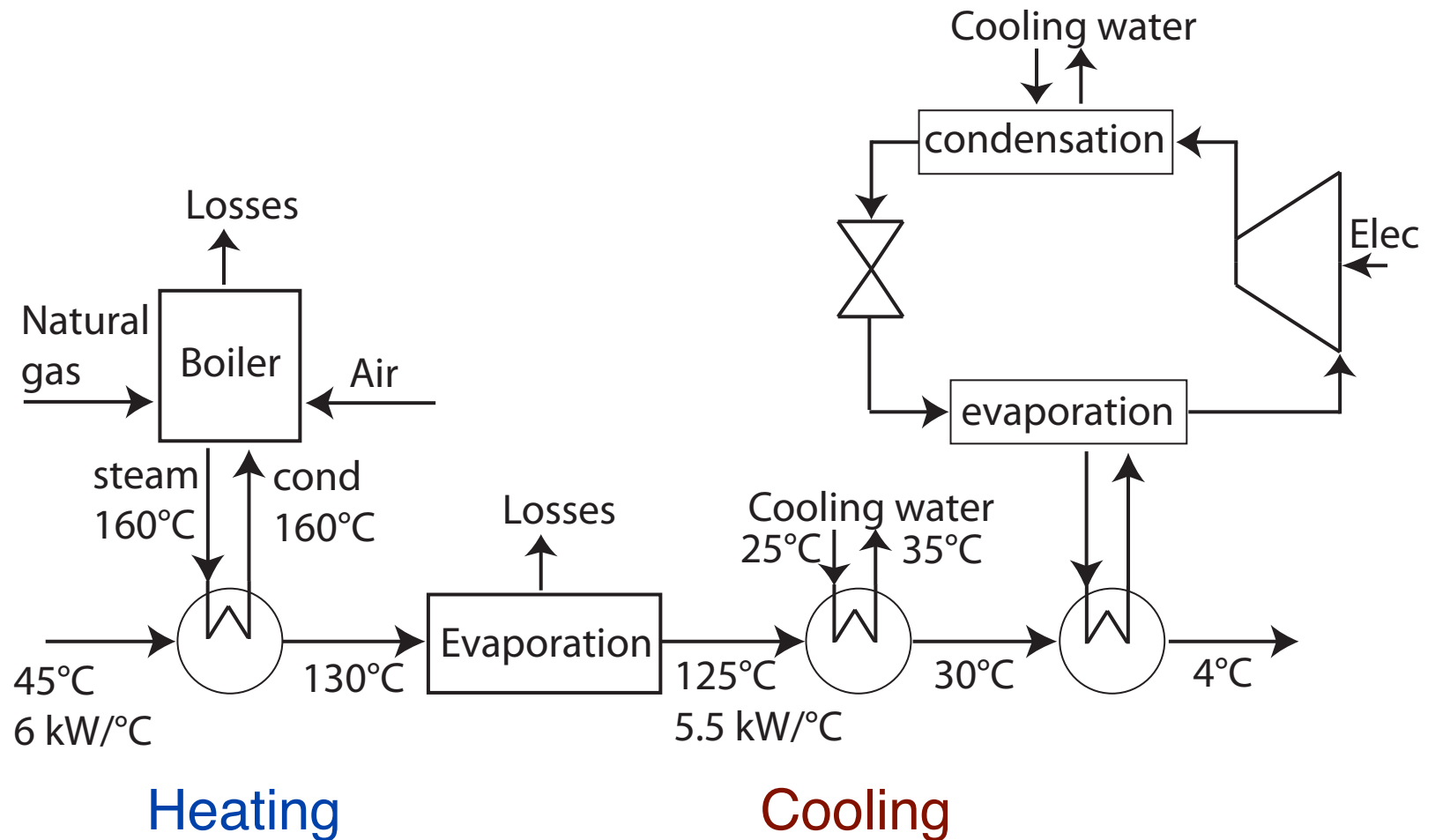
Reduce the energy bill ?



Group work : the A of Agir

- What is needed for evaluating the solution
 - On a sheet of paper
 - 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



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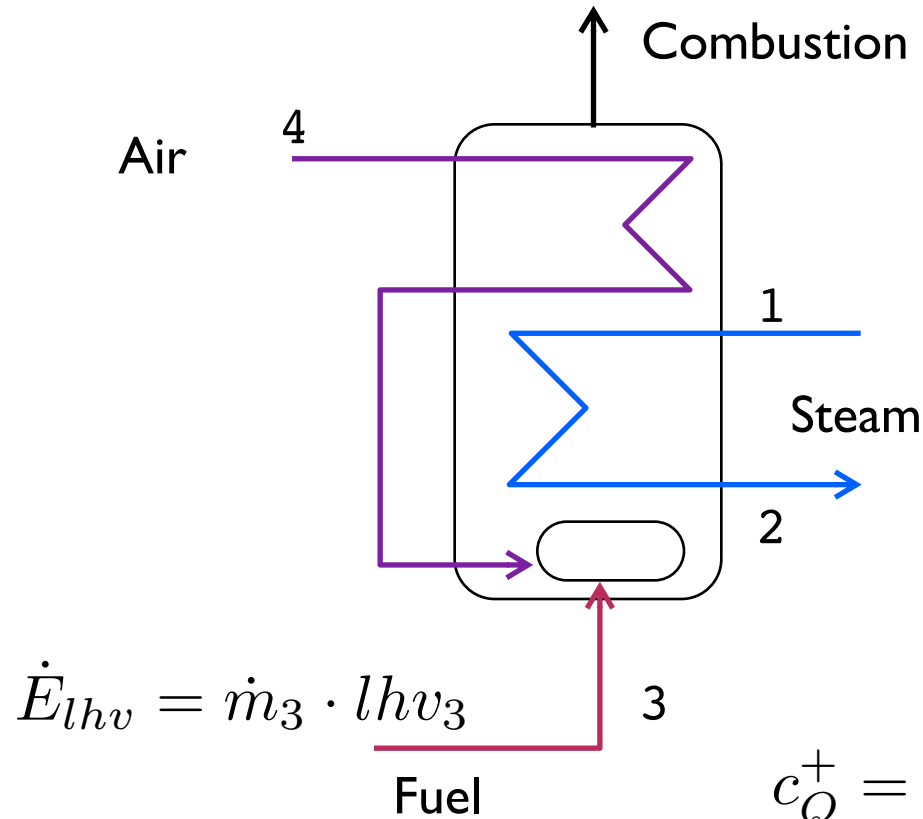
A : What is needed

- **Process modification**
 - New flowsheet : configuration of energy saving
 - Operating conditions
- **Operating cost**
 - Cost of energy
 - $[\text{CHF/k}]_{\text{th}}$
 - Heating/cooling/refrigeration
 - Operating time $\Rightarrow [\text{CHF/year}]$
- **Capital cost**
 - Size of the equipment
 - Investment required $[\text{CHF}]$
 - Annualisation $[\text{CHF/year}]$
 - expected life time
 - Interest rate

Summary

- Streams to heat/cool
- Heat recovery => adding heat exchangers
- Project evaluation
 - buying a new heat exchanger
 - Capital cost (CAPEX)
 - Energy savings
 - Operating cost reduction (OPEX)
$$\Delta OPEX = \int_{years} \dot{m}_{energy}^0(t) c_{energy}(t) dt - \int_{years} \dot{m}_{energy}^{new}(t) c_{energy}(t) dt$$
 - Profitability
 - Compare $\Delta OPEX(+)$ and $CAPEX(-)$

Calculating the cost of energy



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

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

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

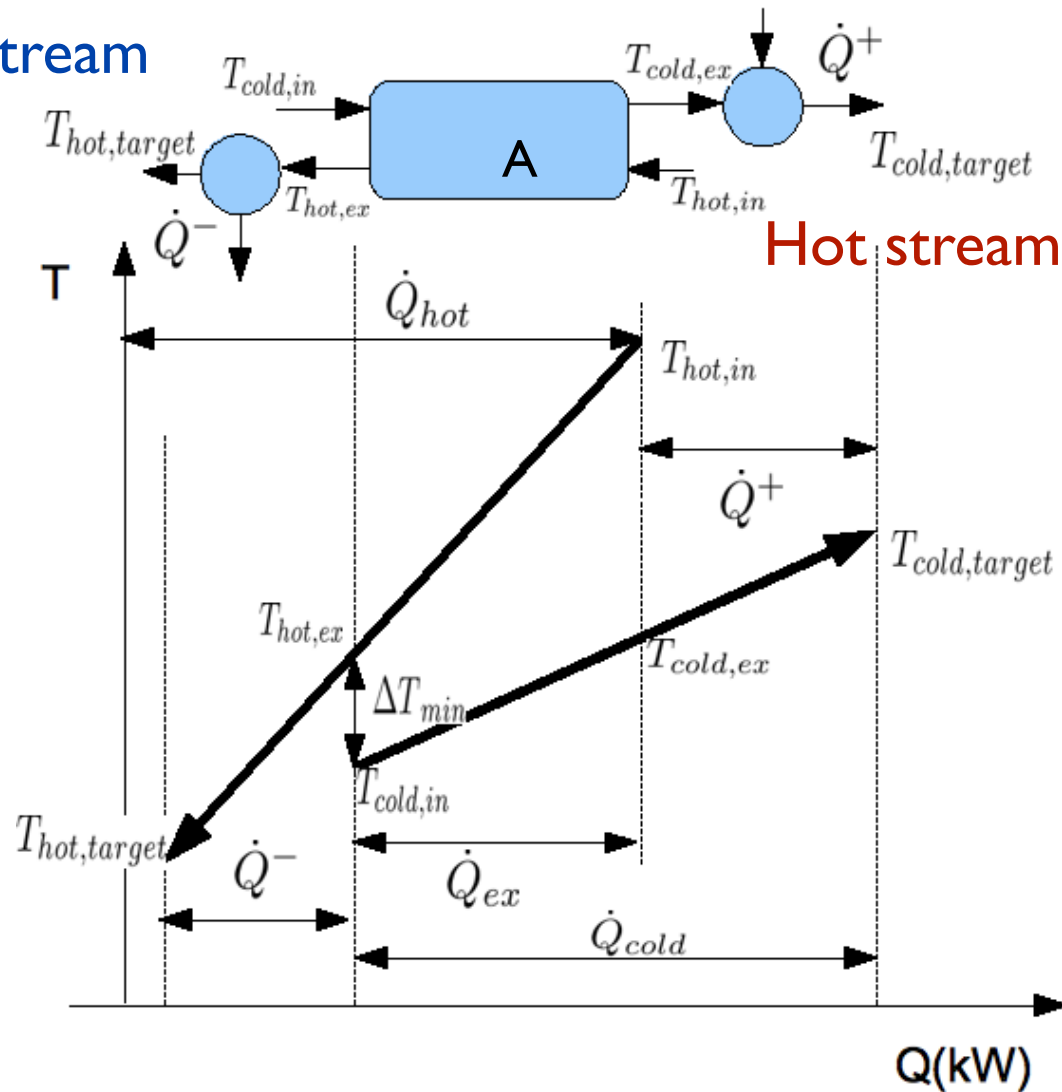
$$C_{fuel} = \int_{t_0}^{t_{year}} (c_{lhv}^+(t) \cdot \dot{m}_3(t) \cdot lhv_3) dt \quad [CHF/year]$$

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Heat recovery : Heat exchanger

Cold stream



Heat exchangers

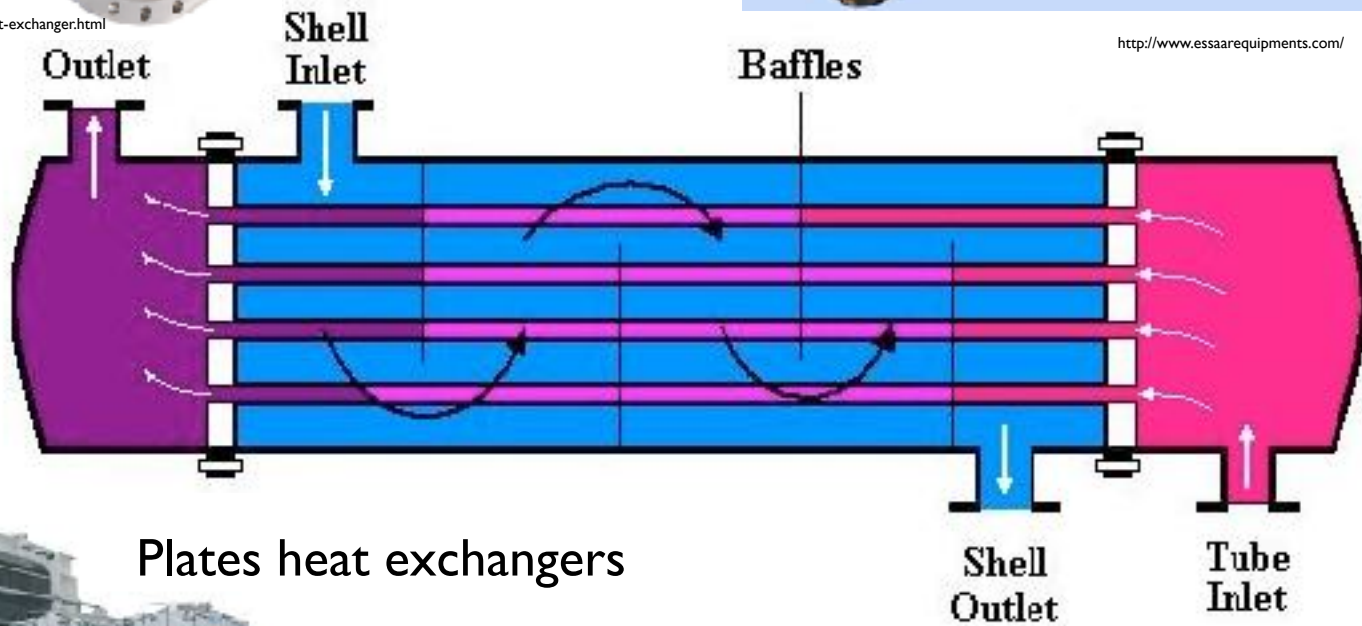


shell and tubes

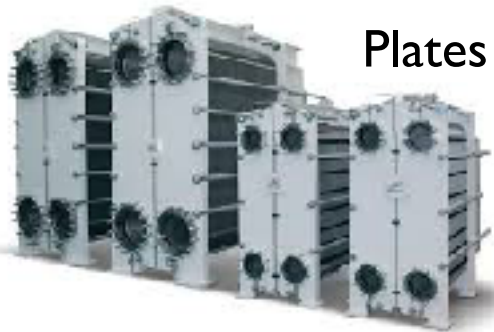


<http://www.techformengineering.com/heat-exchanger.html>

<http://www.essaarequipments.com/>

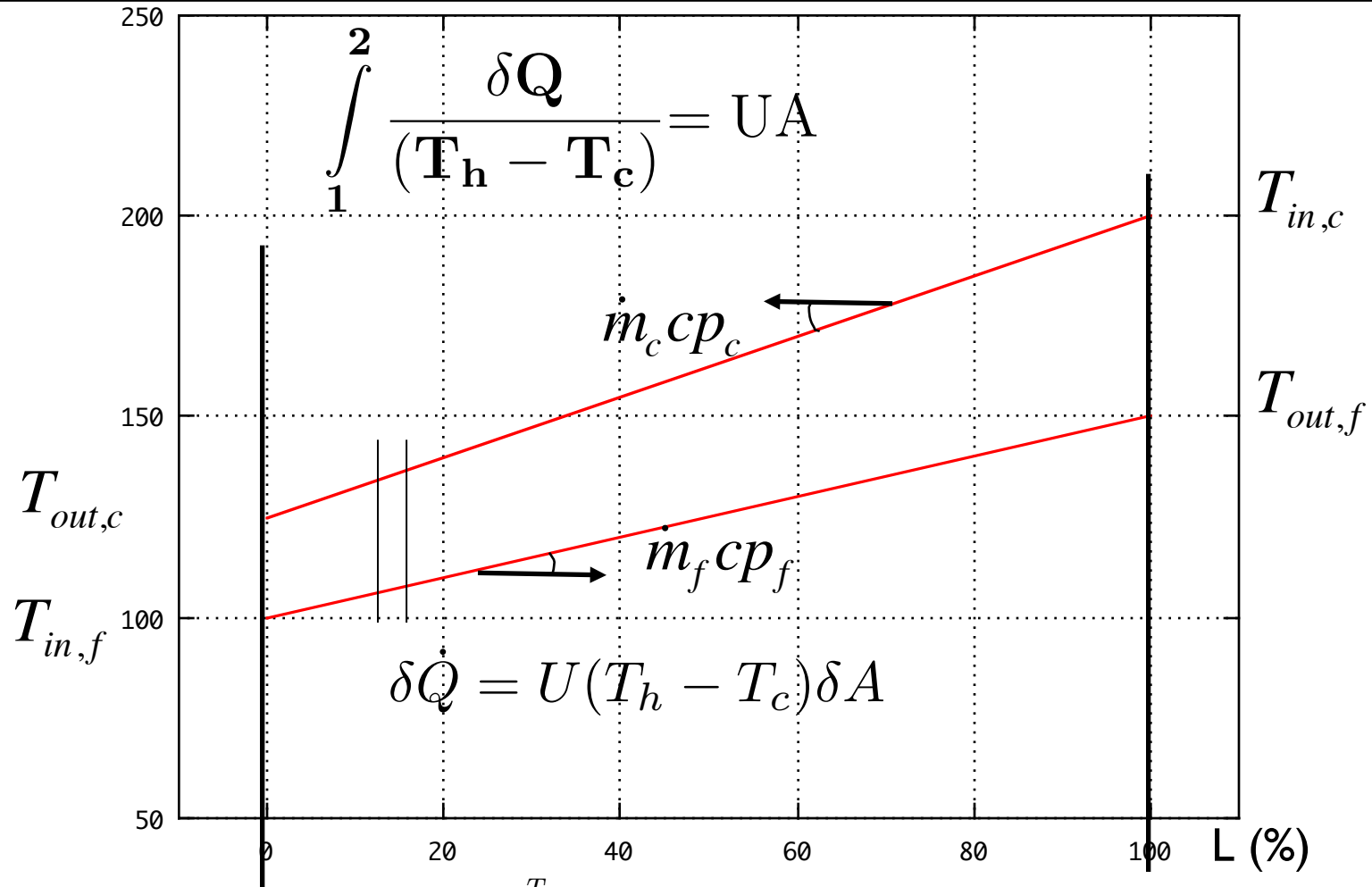


Plates heat exchangers



<http://www.arabianoilandgas.com>

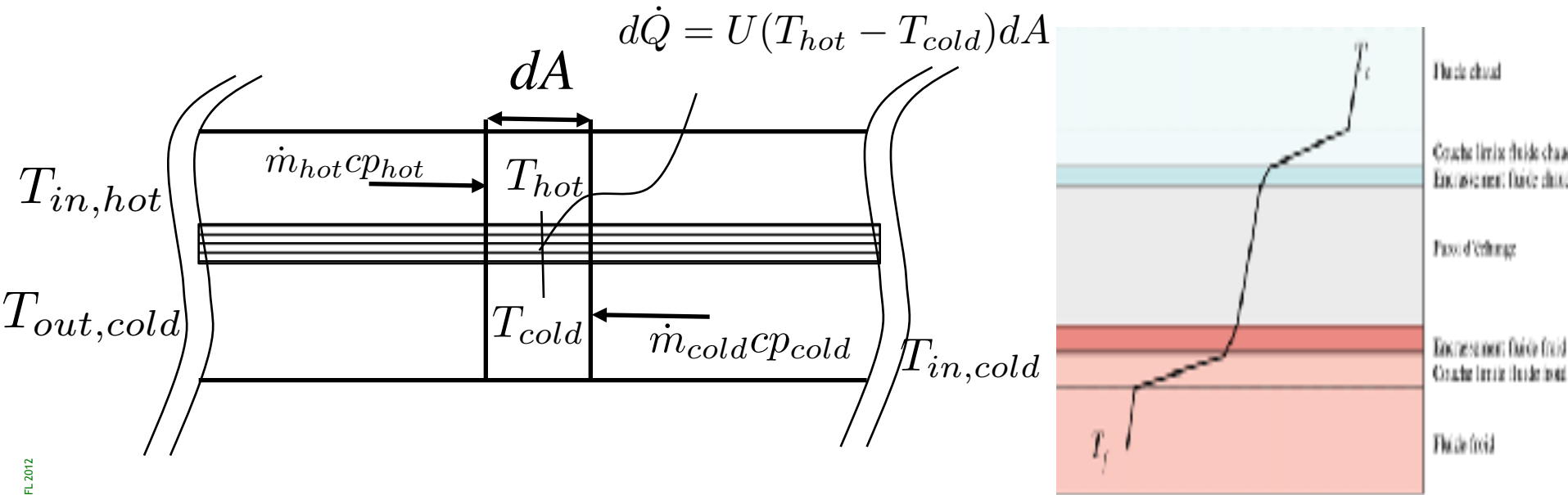
Counter current heat exchanger model



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

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

Heat transfer model



Fluid heat transfer resistance

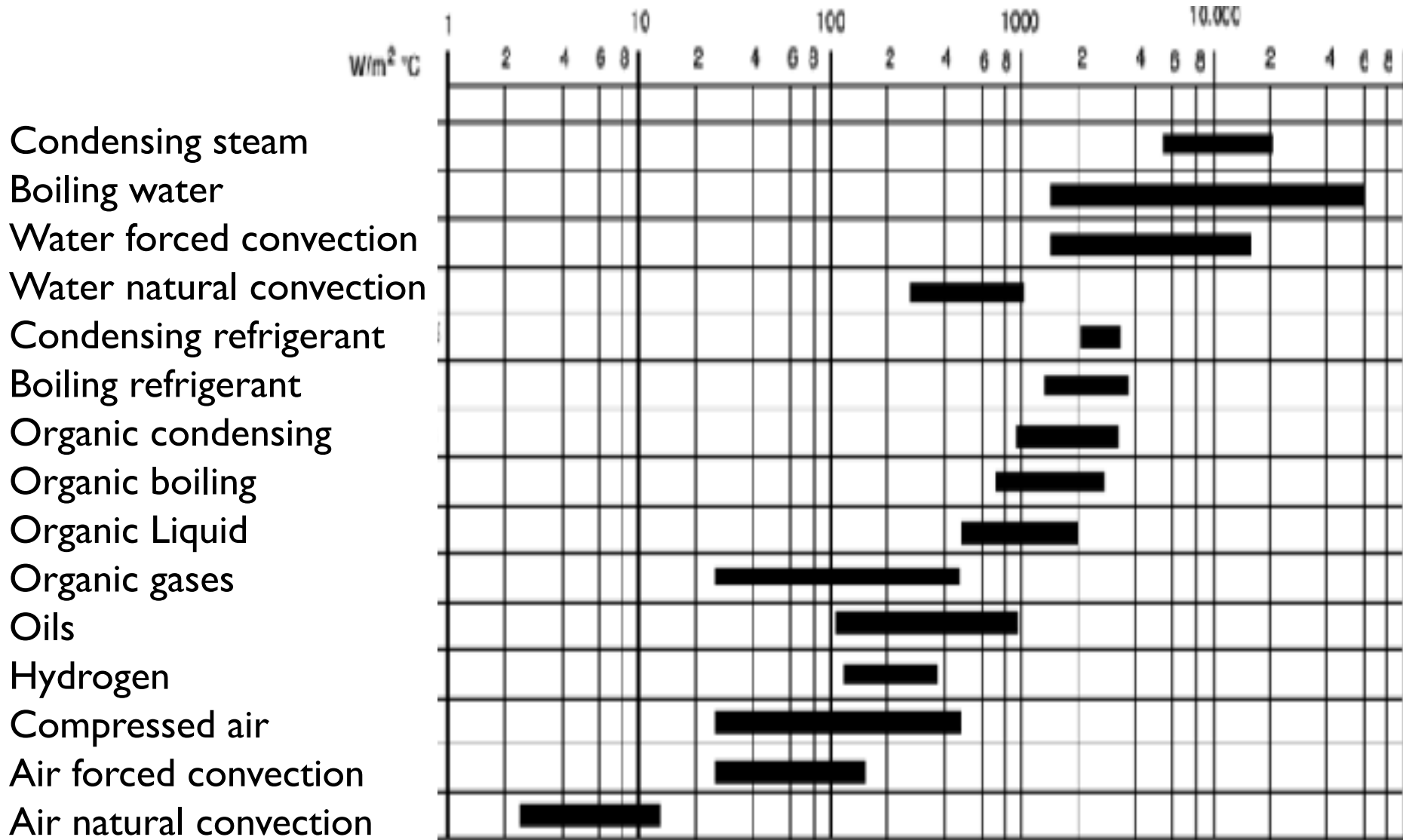
$$\frac{1}{U} \left[\frac{m^2 K}{kW} \right] = \frac{1}{\alpha_{hot}} + \frac{e}{\lambda} + \frac{1}{\alpha_{cold}} + R$$

Conductivity
Often neglected

Fouling

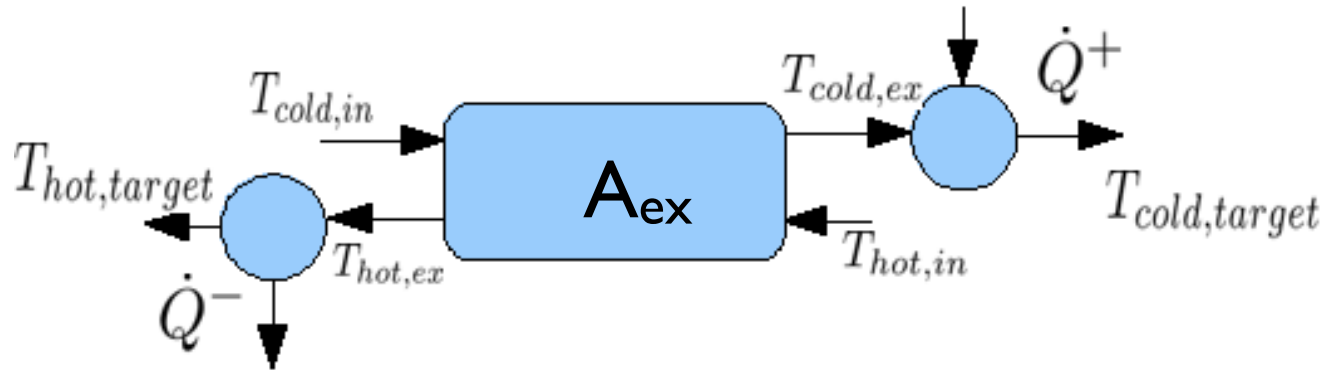
see prof Thome Lectures

Heat transfer coefficient



Heat transfer coefficient table

Heat exchanger model



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

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

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

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

If c_p 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}	$[kW/m^2/K]$
α_{cold}	$[kW/m^2/K]$
α_{hot}	$[kW/m^2/K]$
λ	$[kW/m/K]$
e	$[m]$

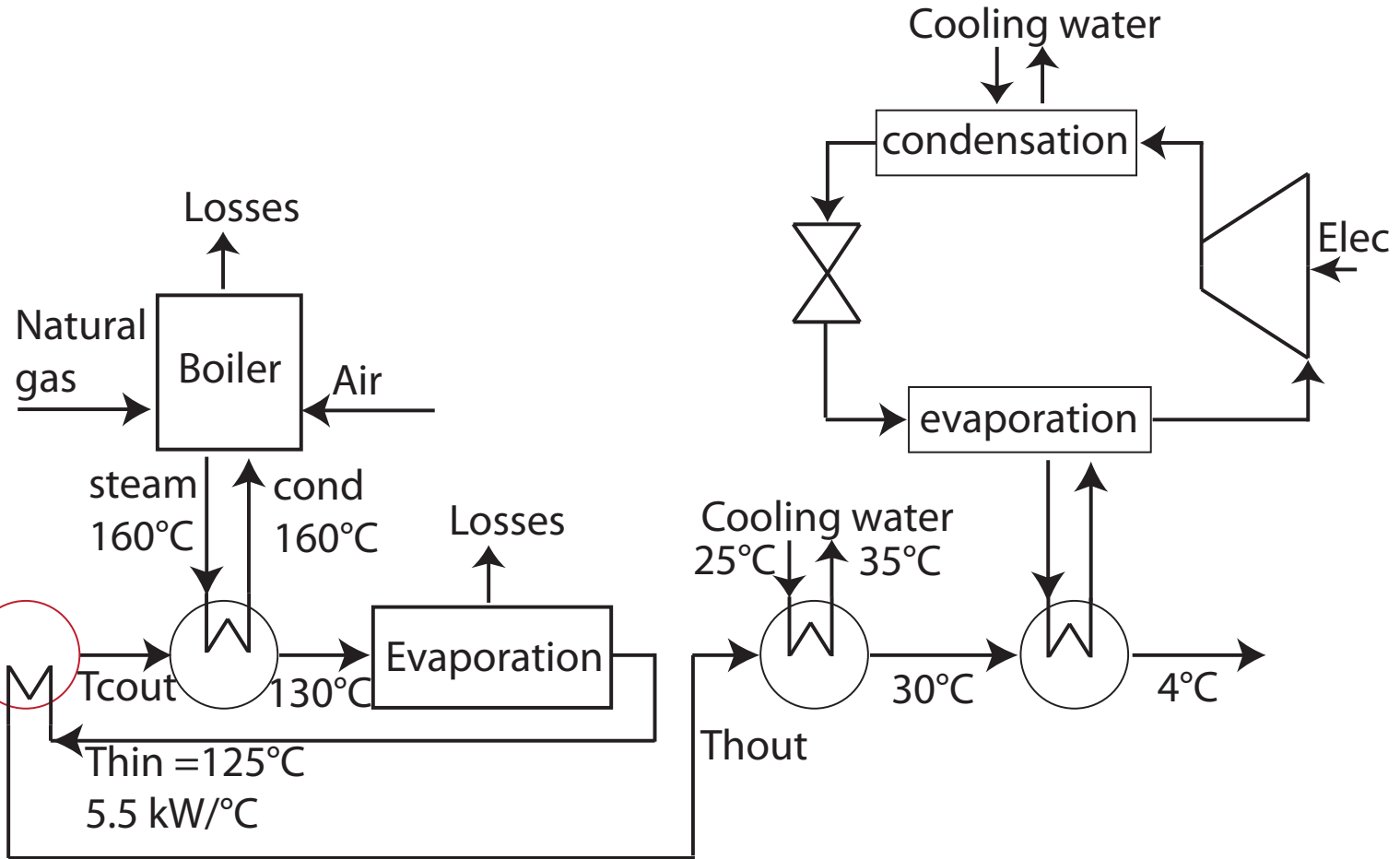
the global heat transfer coefficient of the heat exchanger;
the film heat transfer coefficient of the cold stream;
the film heat transfer coefficient of the hot stream;
the thermal conductivity of the tubes;
the thickness of the tubes.

Estimating the investment

- Estimating the investment
- Annualising the investment

Calculating the optimal value of the DT_{min} In a heat recovery project

Heat recovery by adding a heat exchanger



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

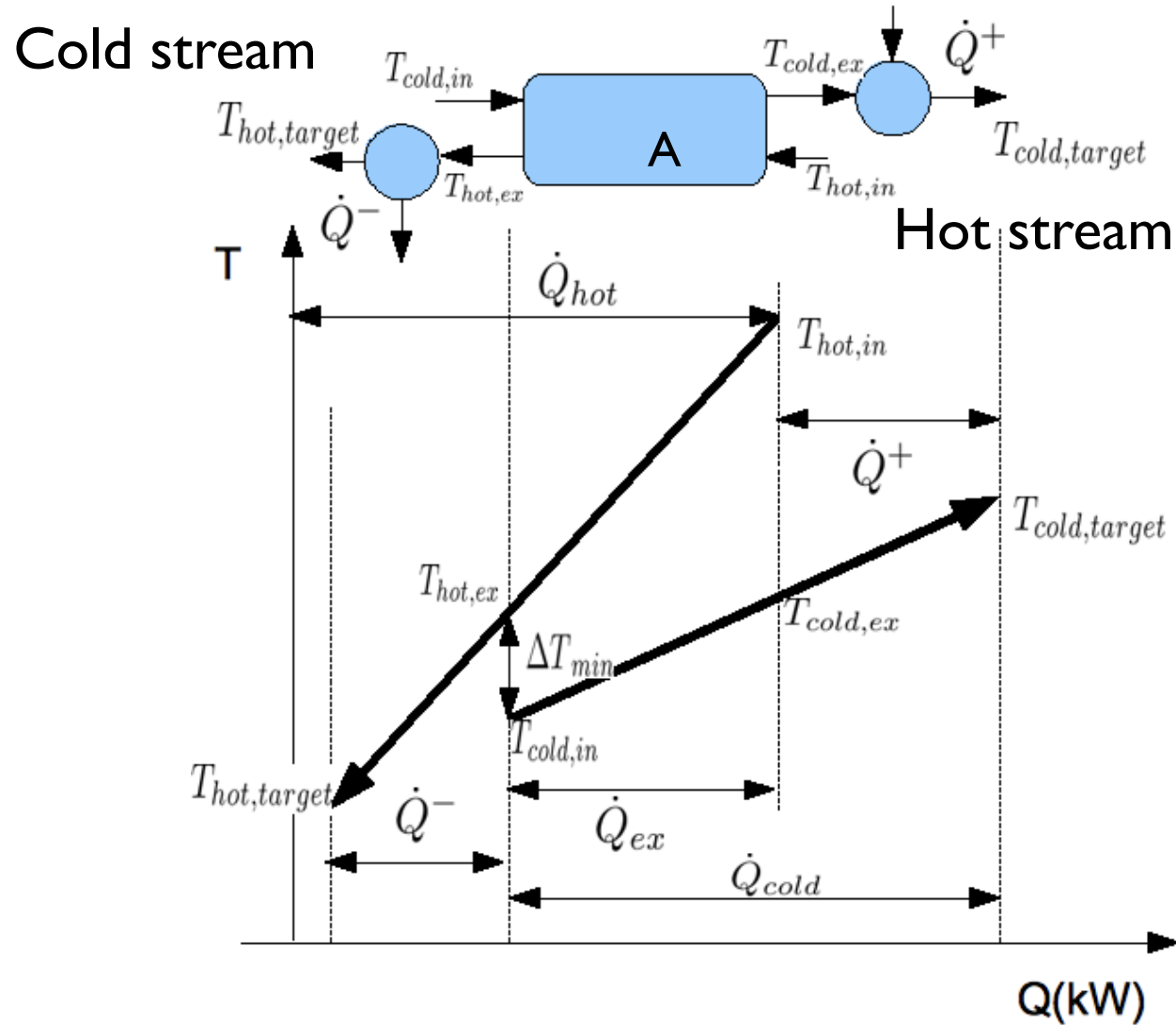
- Operating cost reduction (OPEX)

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

- Profitability

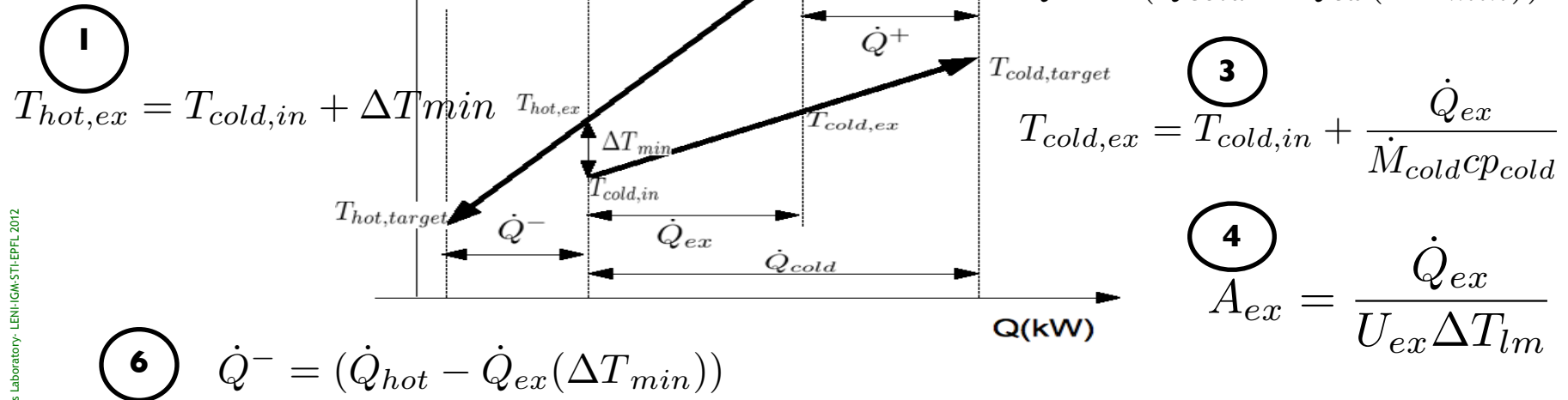
- Compare $\Delta OPEX(+)$ and $CAPEX(-)$

Heat recovery : Heat exchanger



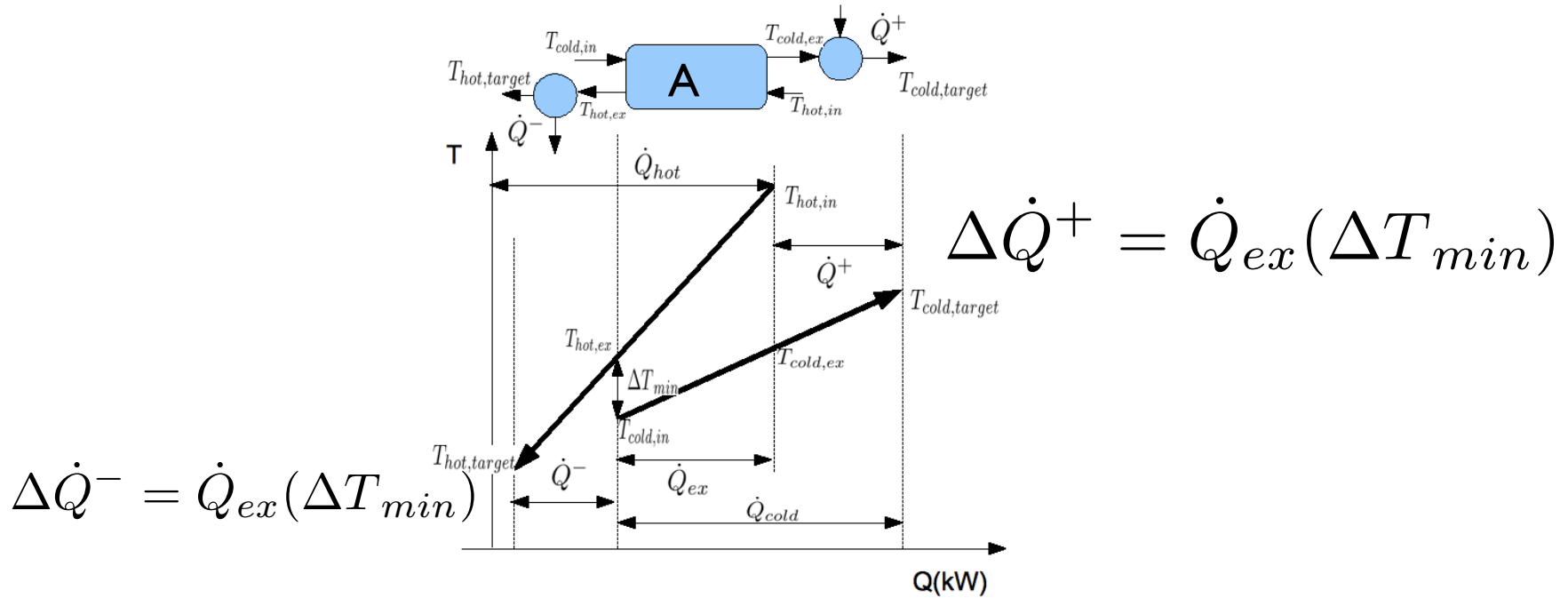
Heat exchanger calculation

$$\textcircled{2} \quad \dot{Q}_{ex}(\Delta T_{min}) = \dot{M}_{hot} c p_{hot} (T_{hot,in} - (T_{cold,in} + \Delta T_{min}))$$



The calculation is made using a sequence of resolution that is established when ΔT_{min} is known.

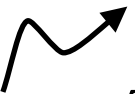
Energy savings values



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

ΔT_{min} value : optimization problem

Decision variable


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

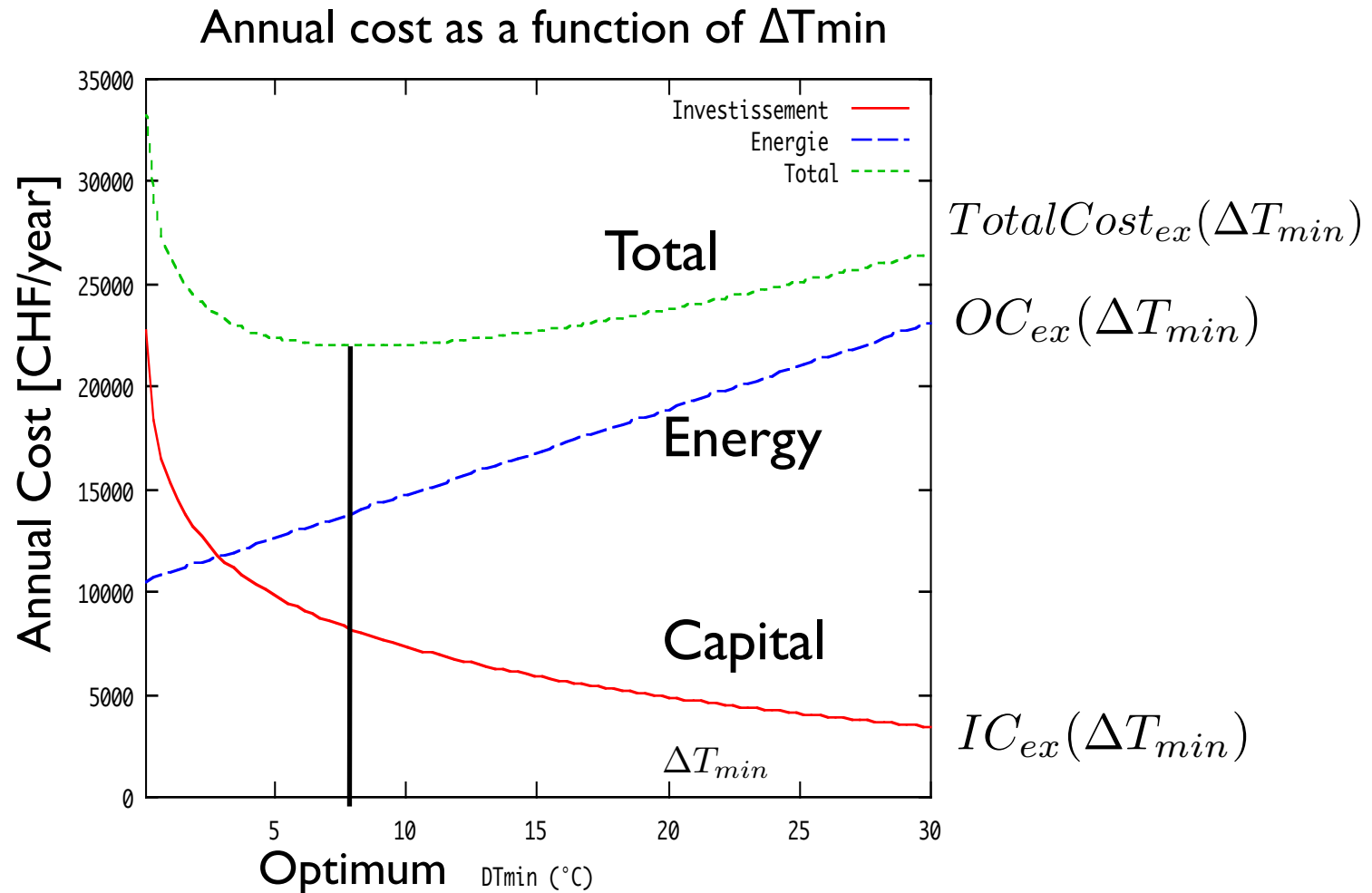


Objective function

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

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

ΔT_{min} value : optimization problem



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

ΔT_{min} value : optimization problem

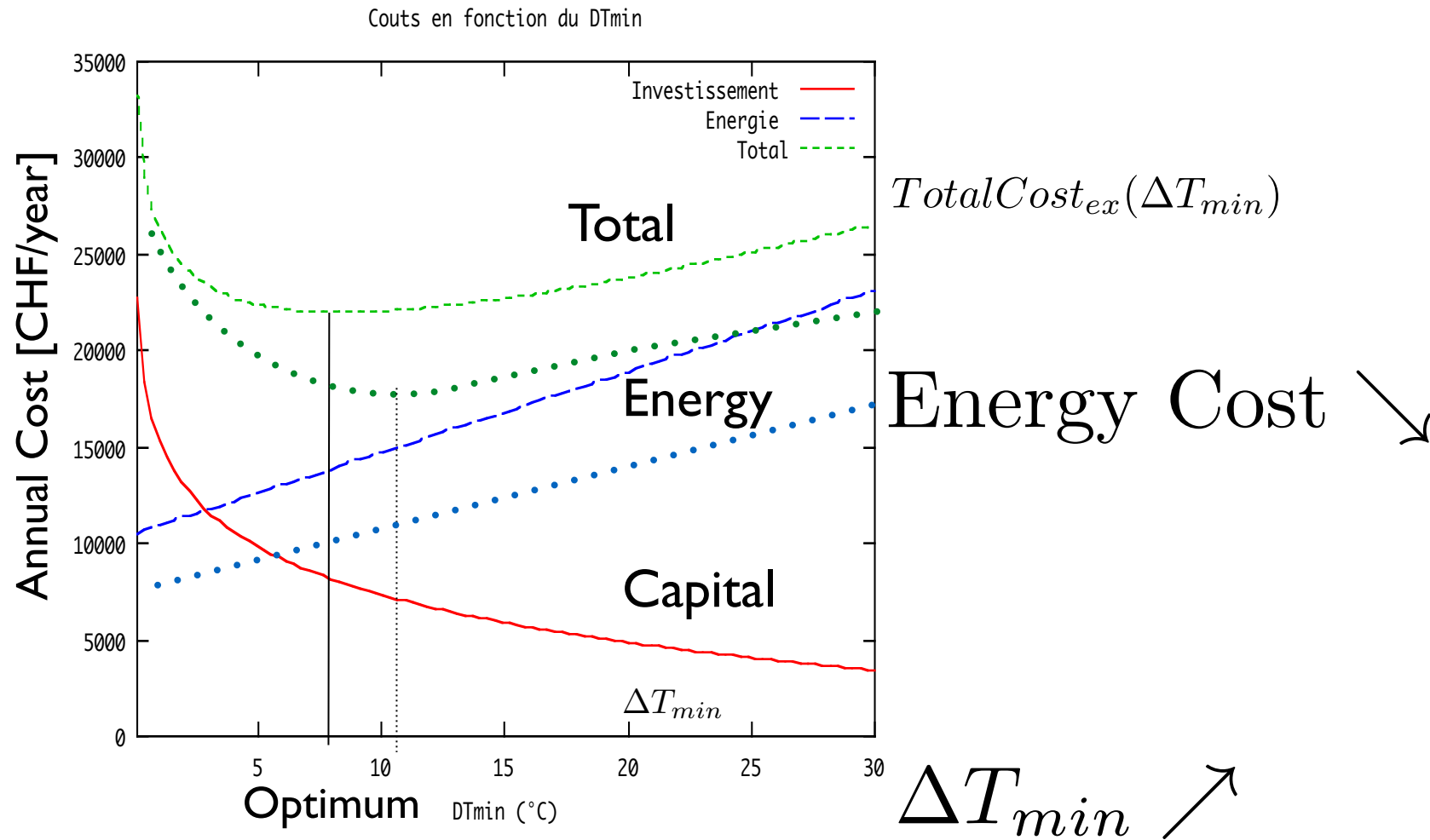
$$\min_{\Delta T_{min}} TotalCost = OC_{ex}(\Delta T_{min}) + IC_{ex}(\Delta T_{min})$$

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

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

- 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

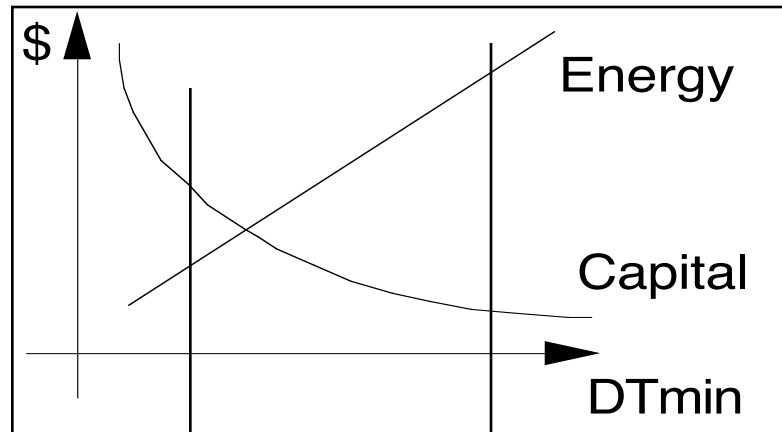
ΔT_{min} value : for cheaper energy cost



What is the ΔT_{min} ?

Minimum approach temperature difference

Energy - Investments Trade-off



Small ΔT_{min}

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

Big ΔT_{min}

- 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**
 - based on the NPV criteria
 - based on return on investment
 - based on internal rate of return
- **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