MODULE 2.1

Energy Efficiency in EINSTEIN

Process Optimisation

and

Heat Recovery

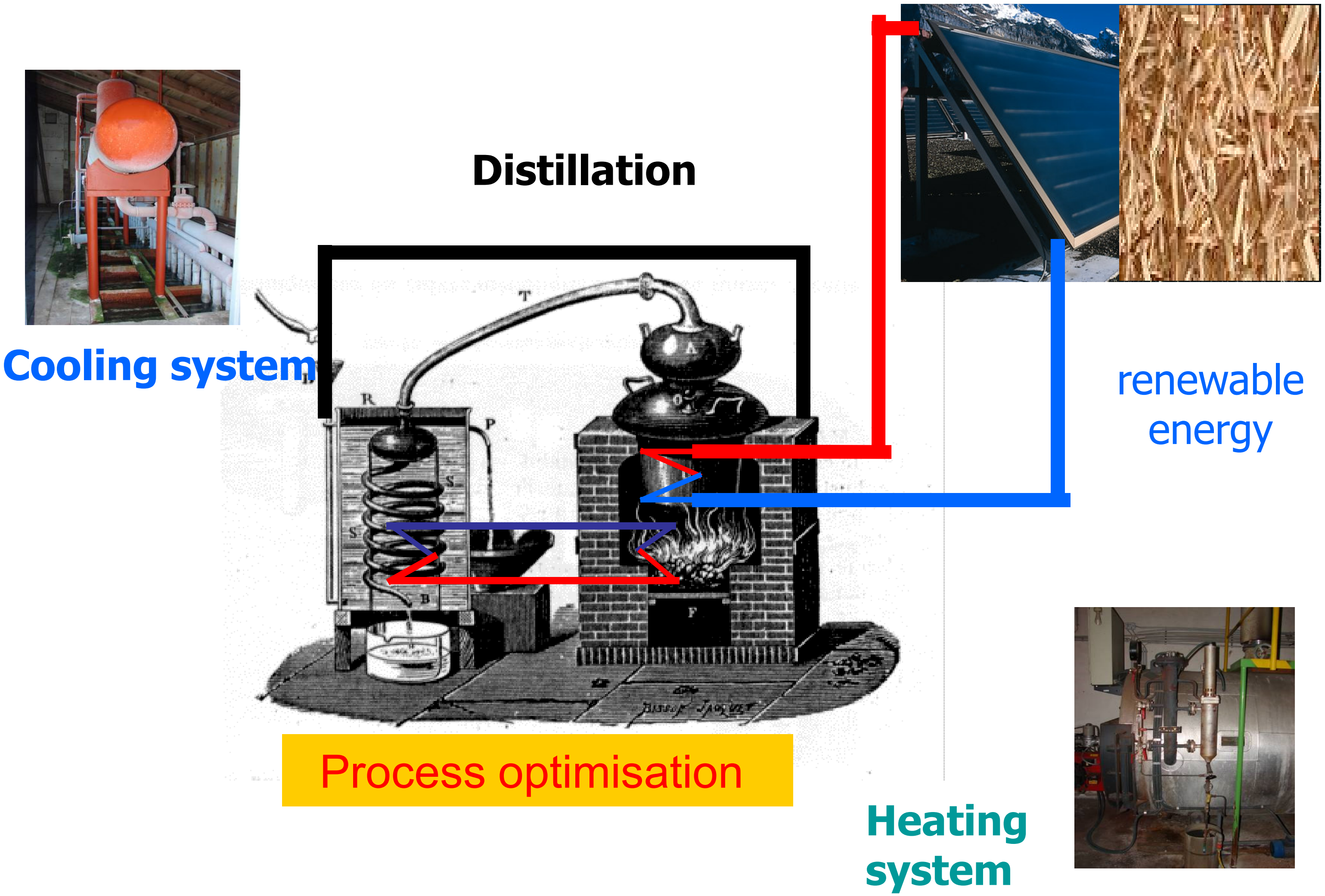
Conceptual design of saving options and draft energy targeting

EINSTEIN thinks logical,

therefore energy savings come first!

- ✓ **On the demand side**
- ✓ **On the supply side**

STEP 7: Conceptual design of saving options and draft energy targeting



STEP 7: Conceptual design of saving options and draft energy targeting

Energy Saving steps:

1. **Reduction of process heat demand through** Process Optimisation
2. **Reduction of required heat supply by** Heat Recovery and Process Integration
3. **Cogeneration and Polygeneration**
4. **Efficient Energy Supply technologies and Renewable energy sources under exergetic considerations**

STEP 7.1 and 7.2: Process Optimization and demand side savings

✓ GOAL

- **Energy improvements of production processes**
- **Improvement of the energy demand of buildings**

✓ Sources of energy efficiency measures

- **BAT Reference Documents (BREFs)**
- **EINSTEIN report on "*Energy Auditing Practices and Tools*" (incl. tools for building optimisation)**
- **Einstein process optimisation** database …

STEP 7.1 and 7.2:
Process Optimization and demand side savings

..a Database for energy efficiency

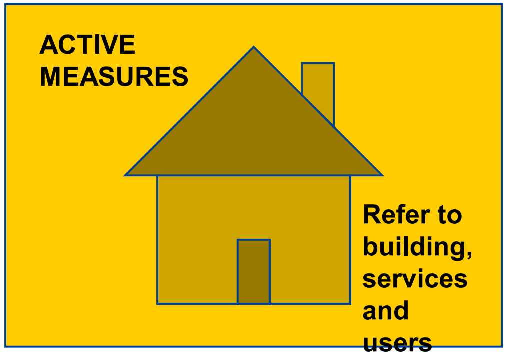
- ✓ **General saving measures / methodologies**
  - **E.g. cascaded use of washing water etc.**
- ✓ **Different technologies for 1 unit operation**
  - **E.g. evaporation – thermal vapour recompression, mechanical vapour recompression, vacuum evaporation etc.**
- ✓ **Efficiency measures that can be applied to specific technologies**
  - **E.g. Waste heat recovery, optimised regulation in drying**
- ✓ **Applicability of technologies/measures to different sectors**
  - **Enabling synergies between solutions applied in different sectors**

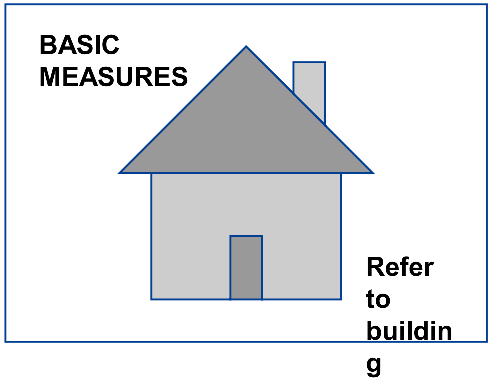
STEP 7.1 and 7.2:
Process Optimization for buildings

→ EINSTEIN uses building heating demands as input for system optimization.

→ Referred to the building, the services and the users *BASIC* and *ACTIVE* measures can be defined.

- ✓ optimized heating system
- ✓ use of renewable energy sources
- ✓ optimized heating control system
- ✓ optimized ventilation system
- ✓ user‘s briefings/ behaviour





- ✓ complete exterior insulation
- ✓ thermal optimized windows/doors
- ✓ airthightness
- ✓ external shadowing
- ✓ natural cooling

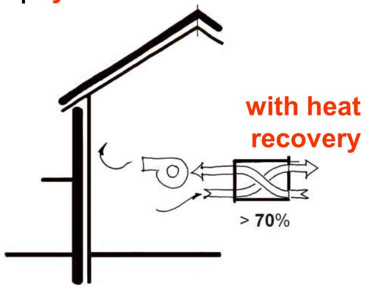
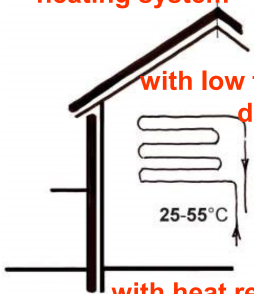
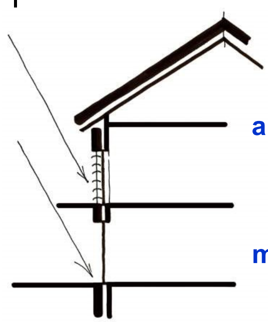
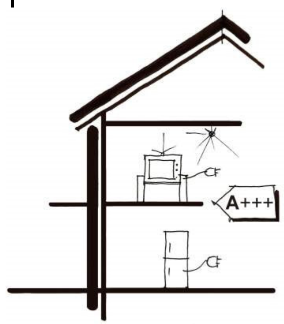
STEP 7.1 and 7.2:
Process Optimization for buildings

The climate zones in the EU can be divided into *warm*, *temperate* and *cool* zones depending on:

- ✓ lowest and average outside temperature during heating period
- ✓ average outside temperature during summer
- ✓ heating degree days
- ✓ solar radiation

STEP 7.1 and 7.2: Process Optimization for buildings

…for heating and cooling in different climate zones

...regarding*	**W** warm	**T** temperate	**C** cool
Heating	insulation, airtightness and optimized ventilation system  with heat recovery	insulation, airtightness, optimized ventilation and heating system  with low temperature distribution... use of renewable energy sources with heat recovery	insulation, airtightness, optimized ventilation and heating system  with heat recovery and use of renewable energy sources
Cooling	natural cooling, external shadowing, user‘s briefing/ behaviour and optimized ventilation  with free cooling	external shadowing, user‘s briefing/ behaviour  and some more natural cooling measures	user‘s briefing/ behaviour and external shadowing 

* Source: AEE INTEC, verified by SQUARE partners

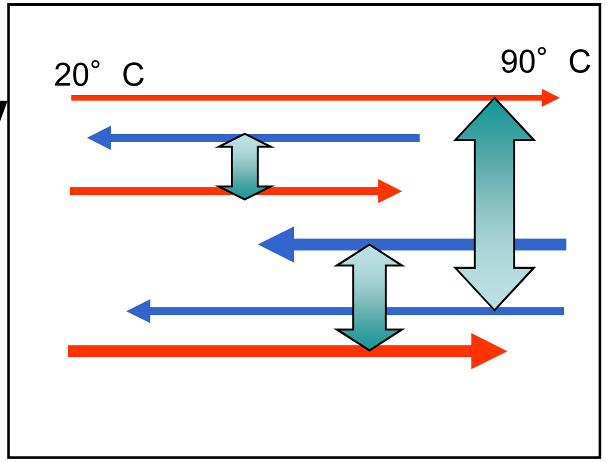
Steps 7.3 and 7.4: theoretical HR potential and pre-design HX and storage

7.3. Heat Recovery POTENTIAL

- ✓ **Analysis of a minimal external heat and cold demand**
- ✓ **Potential for heat recovery**

7.4. Design of heat exchanger networks:

- ✓ **Design and optimization of a heat exchanger network**
- ✓ **Reduced energy demand and required temperature levels → basis for exergetic optimized integration of heat and cold supply**



Steps 7.3 and 7.4: theoretical HR potential and pre-design HX and storage

- ✓ **Placement of the design of the heat recovery system within the audit methodology:**
  - ✓ **Prior to new energy supply design**
  - ✓ **Possible re-calculation with new supply systems**
    - **Energy streams based on heat/cold generation equipment could change**

Steps 7.3 : theoretical HR potential

✓Goal:

Theoretical potential of energy savings by heat recovery (prior to energy supply systems design)

- **Save fuels and avoid over-dimensioning of supply equipment**

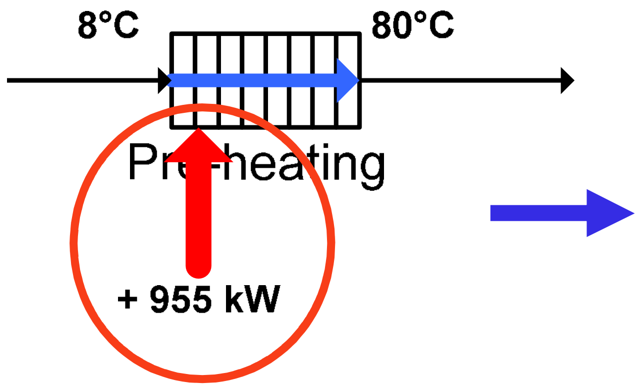
✓Methodology

- **From energy supply and processes to „streams"**
- **Pinch Analysis**
  - **Hot and cold composite curve**
  - **Grand composite curve**

✓Results:

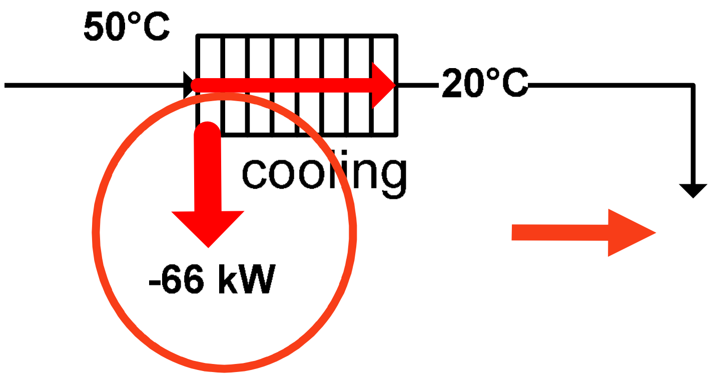
- **Theoretical heat recovery potential**
- **Necessary external heat/cold supply at the different temperature levels**

Steps 7.3 : theoretical HR potential



„Cold streams“ **need to be heated**

Any process in which energy input is needed **for heating the process flow/stream**



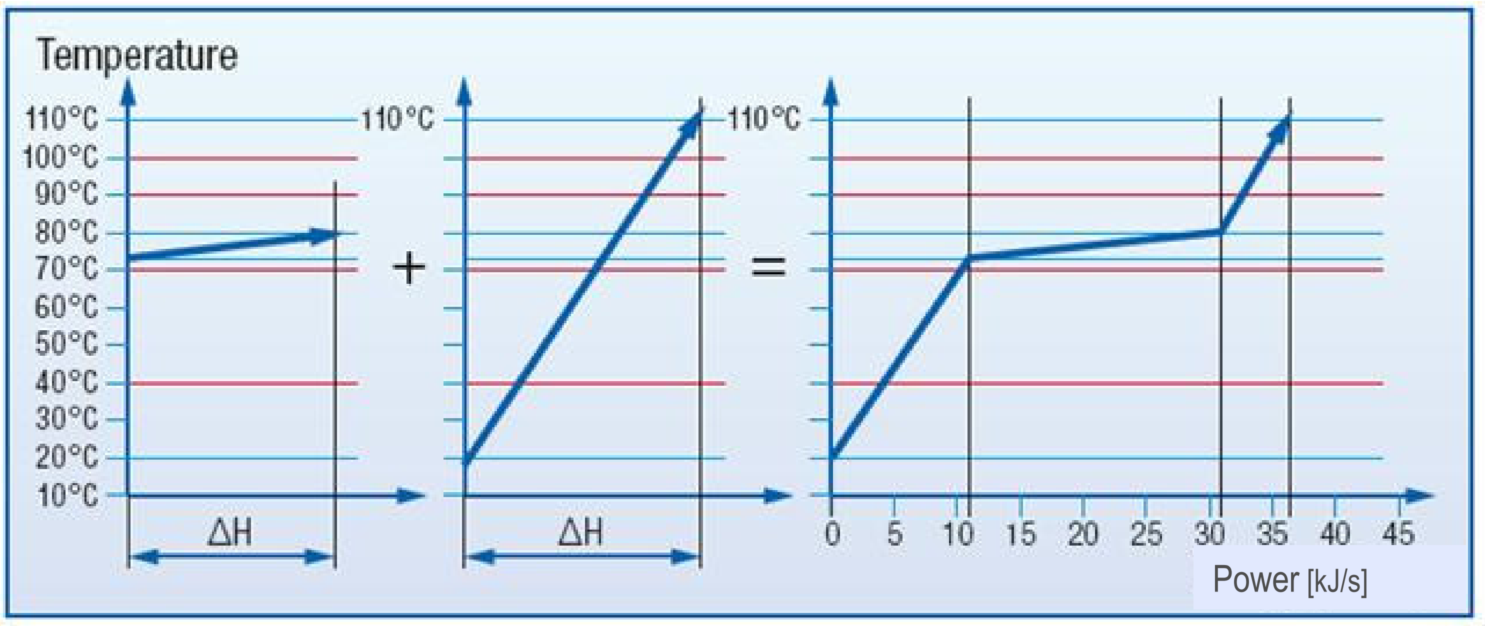
„Hot streams“ **need to be cooled**

Any process in which energy input is withdrawn **for cooling the process flow/stream**

Steps 7.3 : theoretical HR potential

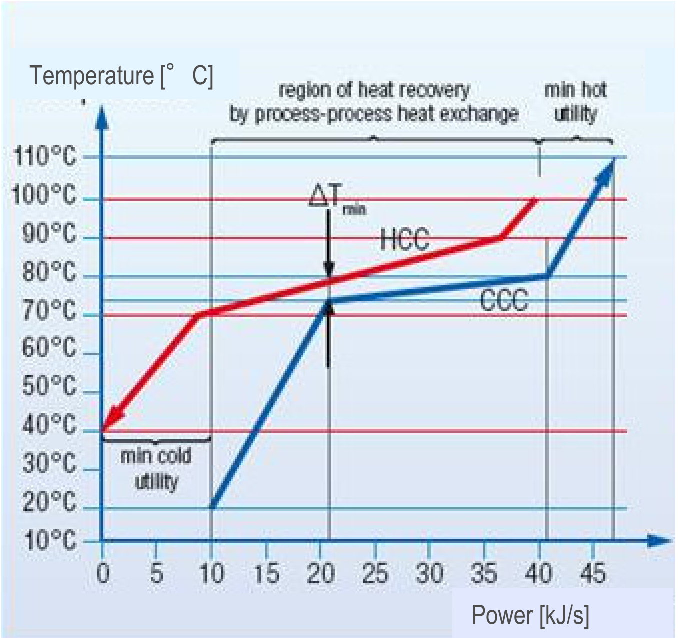
✓ **Composite Curves:**

Adding of vectors representing the energy demand in power and temperature (= energy streams“)



Steps 7.3 : theoretical HR potential

- ✓ **Hot and cold composite curves**
  - ✓ **Pinch temperature – separation of production system in two halves:**
    - **Above pinch – no cooling is necessary**
    - **Below pinch – no heating is necessary**
    - **No energy should be transferred across the pinch (efficient thermodynamic use of energy)**

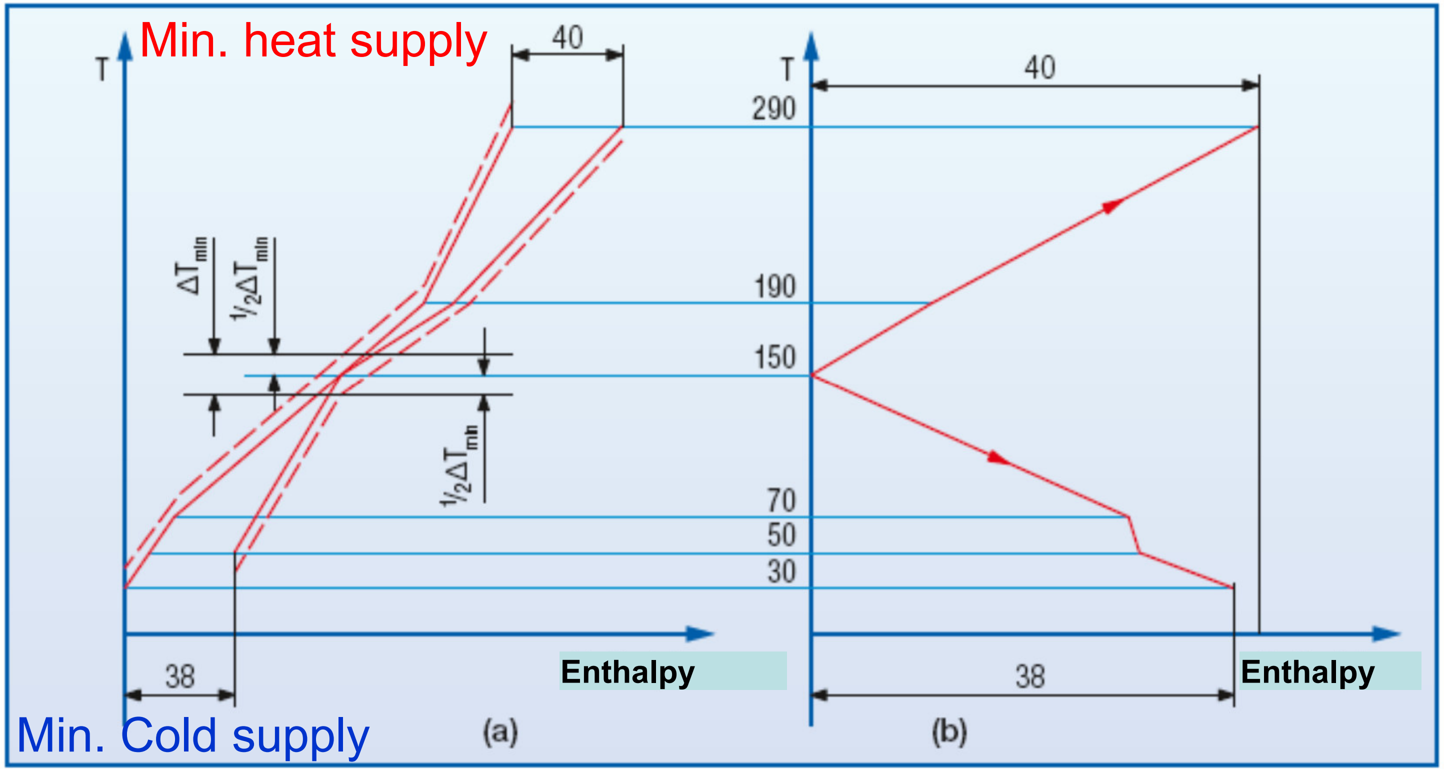


Steps 7.3 : theoretical HR potential

✓ Grand Composite Curve (GCC)

✓It shows

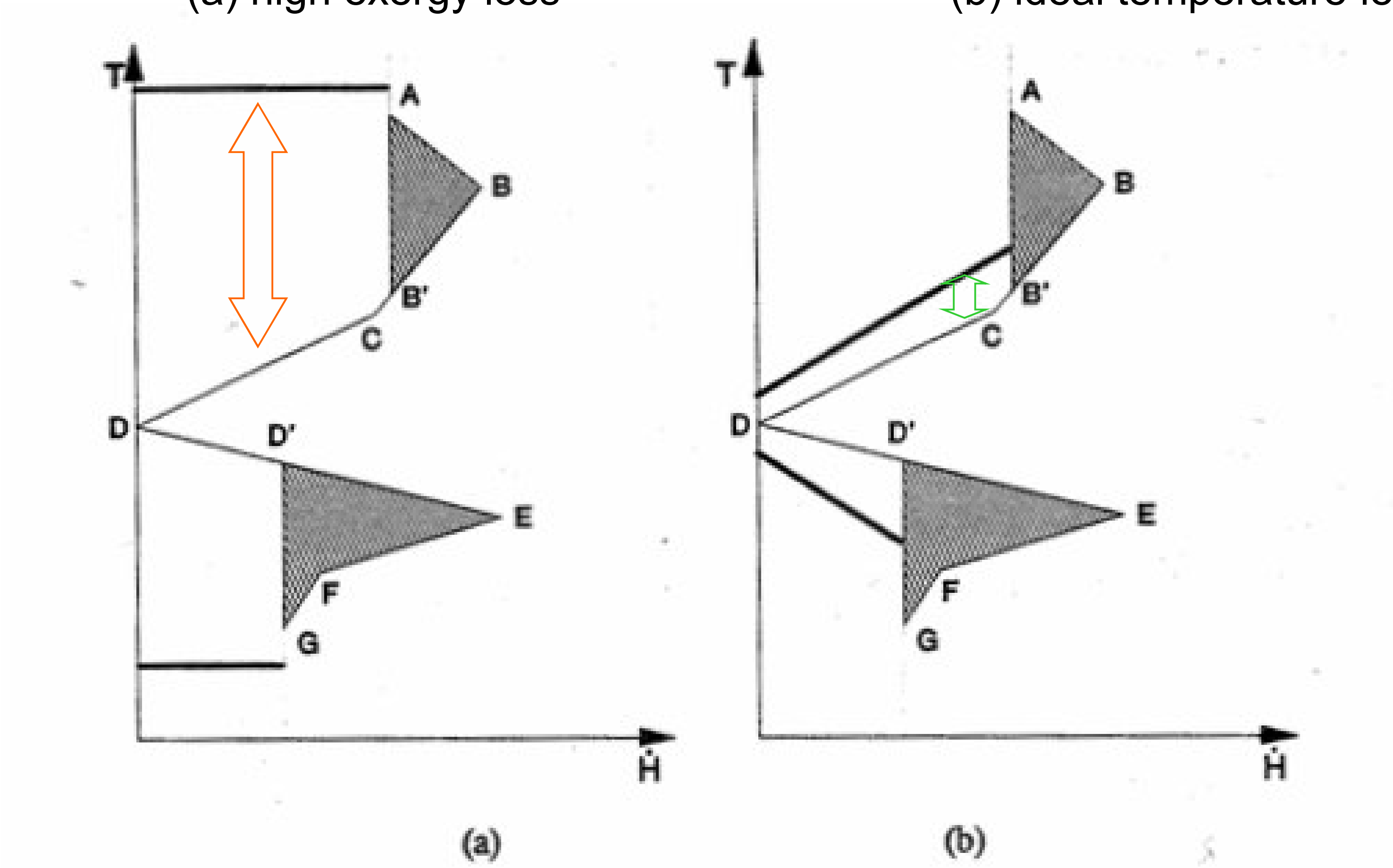
- **The ideal external energy supply necessary to heat up or cool down the streams.**
- **At which temperature the external resource should be supplied**



Steps 7.3 : theoretical HR potential

✓ Grand Composite Curve (GCC) and heat supply

(a) high exergy loss (b) ideal temperature level



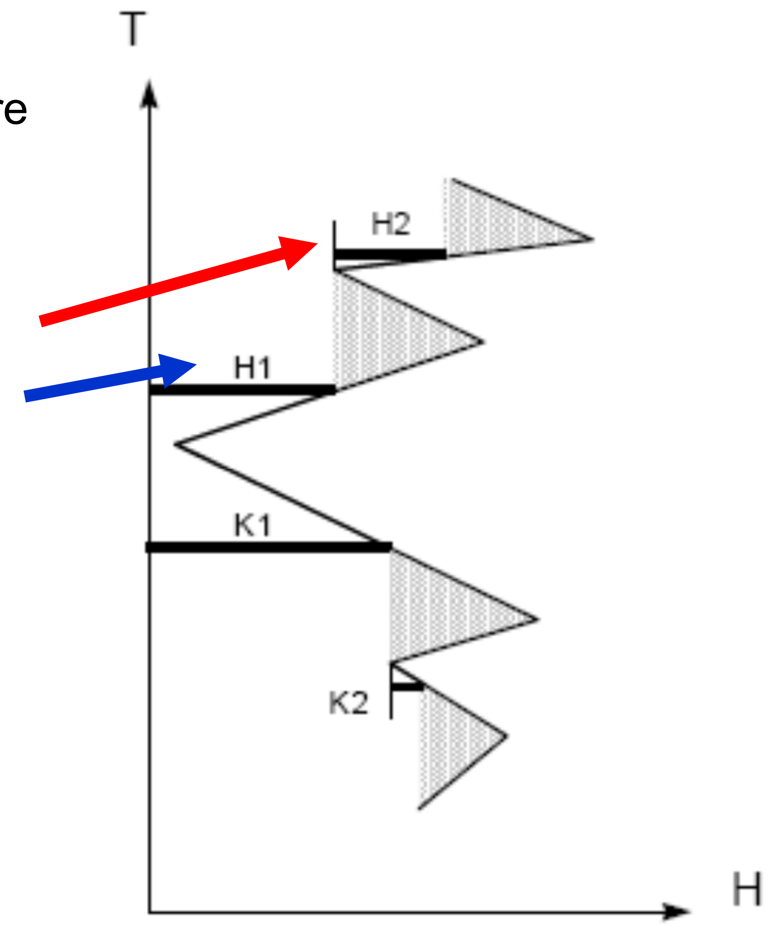
Steps 7.3 : theoretical HR potential

✓ Grand Composite Curve (GCC) and heat supply

Approximation to ideal temperature by heat supply cascade:

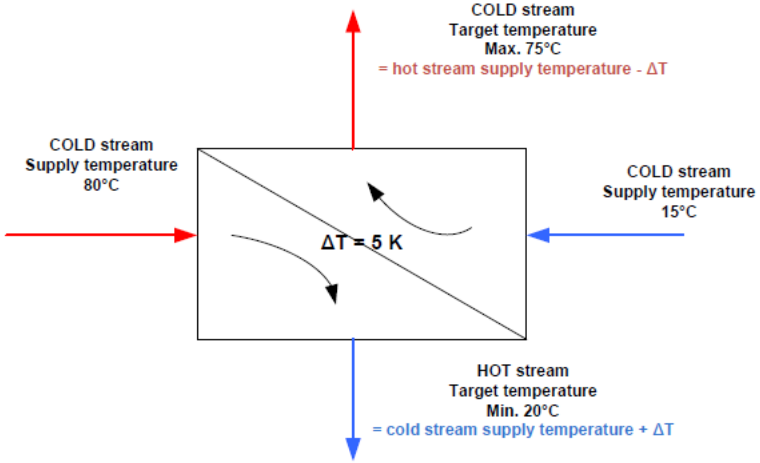
H2: high temperature heat supply

H1: low temperature heat supply



Steps 7.3 : theoretical HR potential

- **Choice of ΔT_{min} for a first concept**
  - **In a counter current heat exchanger the final temperature of the cold stream can at a maximum reach the start temperature of the hot stream minus ΔT_{min}.**
  - **In a counter current heat exchanger the final temperature of the hot stream can at a minimum reach the start temperature of the cold stream plus ΔT_{min}.**



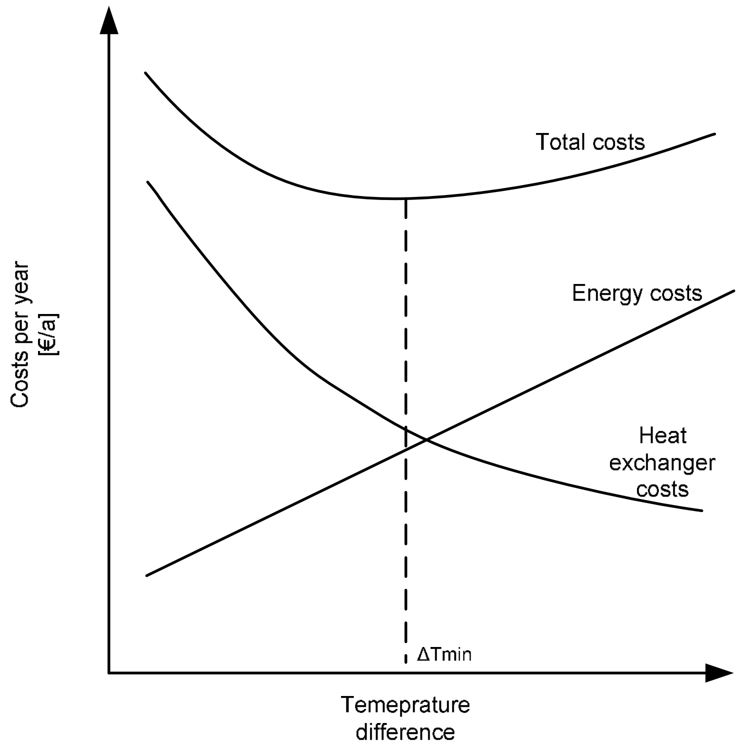
$$H[kW] = m_{hs} * c_{p_{hs}} * \left(T_{supply_{hs}} - T_{target_{hs}}\right) = m_{cs} * c_{p_{cs}} * \left(T_{target_{cs}} - T_{supply_{cs}}\right)$$

Steps 7.3 : theoretical HR potential

✓ Economic optimisation

✓ **Investment costs:** surface area of heat exchange, **temperature, pressure, material of heat exchanger, connections etc.**

✓ **Energy savings:** heat transfer coefficient **(flow characteristics, fluid parameters, material etc.),** logarithmic temperature difference **between the fluids,** surface area of heat exchange

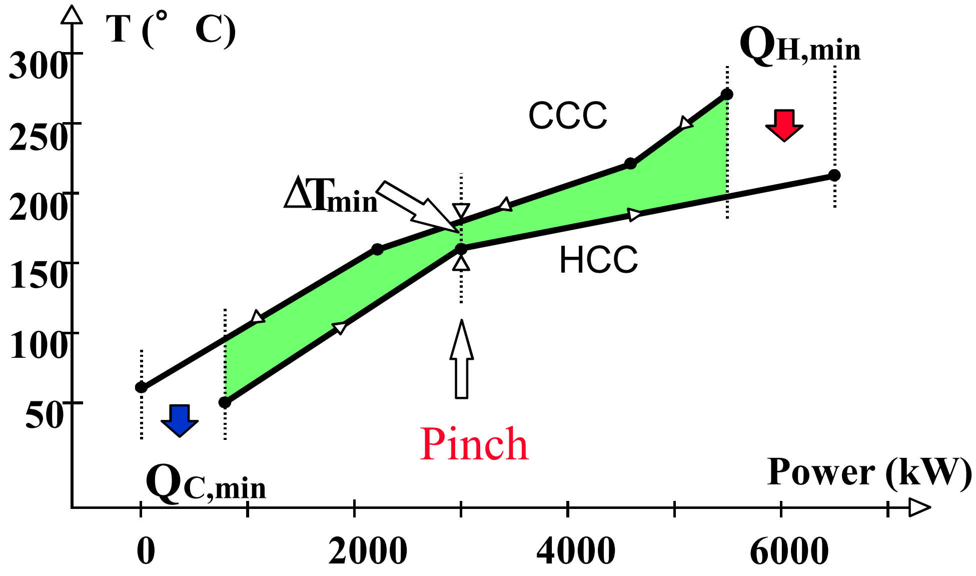


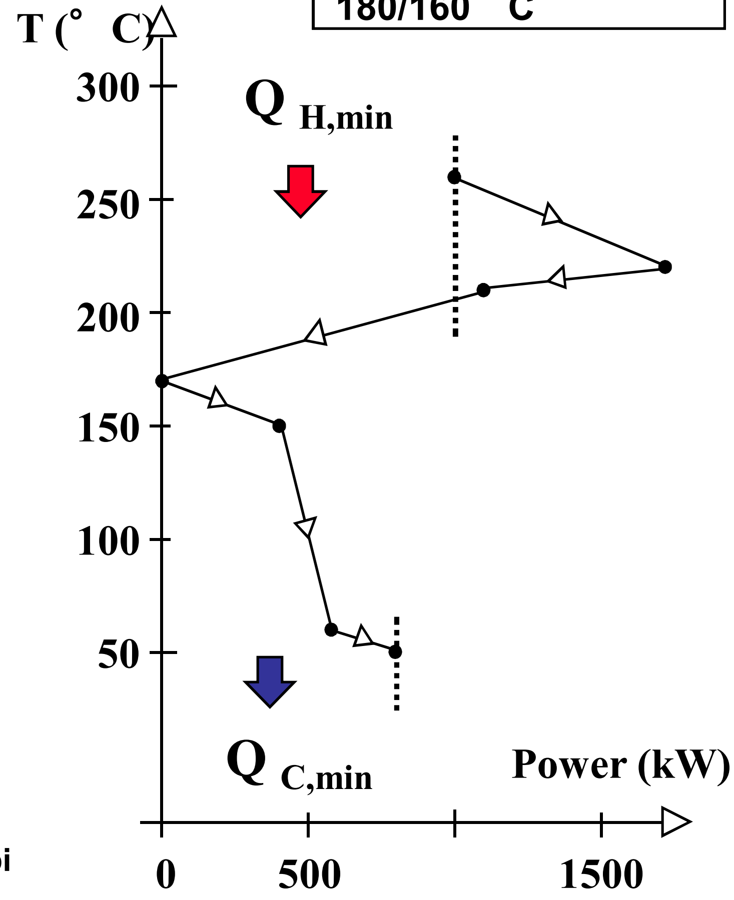
Steps 7.3 : theoretical HR potential

✓ Pinch Analysis

- **Hot and cold composite curve**
- **Grand composite curve**

ΔT_{min} = 20 K
$Q_{H,min}$ = 1000 kW
$Q_{C,min}$ = 800 kW
T_{pinch} = 180/160° C

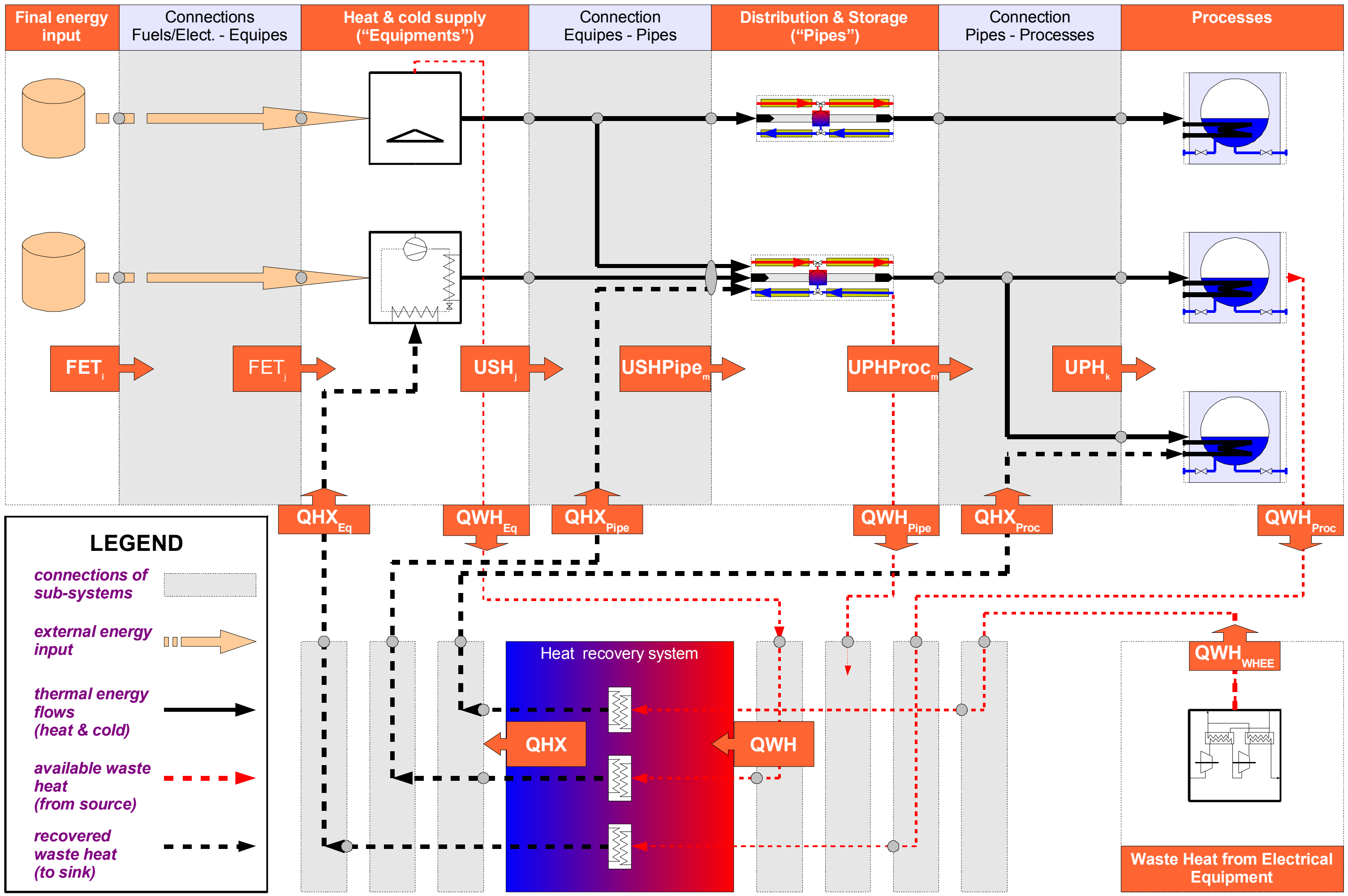




Source: T. Gundersen. IEA. Process Integration, www.tev.ntnu.no/iea/pi

Steps 7.3 : theoretical HR potential

Streams in EINSTEIN - Energy flows



Steps 7.3 : theoretical HR potential

The following enthalpy streams will be used in the pinch analysis (list is not exhaustive):

✓Processes

- **Start up stream (heating up at startup)**
- **Circulation streams (heating of inflowing media)**
- **Maintainance stream (losses and evaporation)**
- **Waste heat streams**
  - **Hot products**
  - **Hot waste water**
  - **Vapours**
  - **Etc.**

Steps 7.3 : theoretical HR potential

The following enthalpy streams will be used in the pinch analysis (list is not exhaustive):

- ✓Distribution Lines
  - **Condensates**
  - **Waste streams from pipes (hot air, hot waste water,…)**
  - **Boiler feed-water Preheating**
  - **Etc.**
- ✓Equipment
  - **Boilers**
    - **Off gas**
    - **Combustion Air**
  - **Waste heat of Chillers**
  - **Heat demand of heat pumps**
  - **Etc.**
- ✓Electric equipment
  - **Waste heat of electric compressors**

Steps 7.3 : theoretical HR potential

✓ From energy supply and processes to streams

✓ Process = Washing

- Volume of vessel: 5 m^3
- Cold water Temperature = 10° C
- Process Temperature = 60° C
- Cold water input = 10 m^3/d
- Heat input during operation (heating of input water and thermal losses, evaporation negligible) = 90 kW
- Operation schedule:
  - Start-Up 6:00 h to 6:30 h
  - Continuous operation 6:30 h to 16:00 h
- Wastewater temperature = 50° C
- Temperature to which the wastewater can be cooled down: 5° C.

Steps 7.3 : theoretical HR potential

✓ From energy supply and processes to streams

✓Process = Washing

→ Enthalpy Streams

Name	Start Temp.	End Temp.	Mass flow	Required Power / Waste Heat	Operation Schedule
	° C	° C	kg/h	kW	
StartUp	**10**	**60**	**10.000**	**582**	**6:00 – 6.30**
Heating continuous inflowing water	**10**	**60**	**1.053**	**61**	**6:30 to 16:00**
Additional heat input during operation for thermal losses	**60**	**60**	**-**	**29**	**6:30 to 16:00**
Wastewater	**50**	**5**	**1.053**	**55**	**6:30 to 16:00**
Wastewater after machine stop	**50**	**5**	**10.000**	**524**	**16:00 – 16:30**

Step 7.4: Pre-design of heat exchangers network

- Goal:
  - **Heat integration with a holistic approach**
  - **Design of a heat exchanger network**
- Methodology
  - **Heat exchanger network design proposal based on pinch analysis**
  - **Heat Exchanger Simulation**
- Results:
  - **Heat Exchanger Network**
  - **Resulting energy demand curves and energy availability curves (yearly energy demand, temperature levels)**

Step 7.4: Pre-design of heat exchangers network

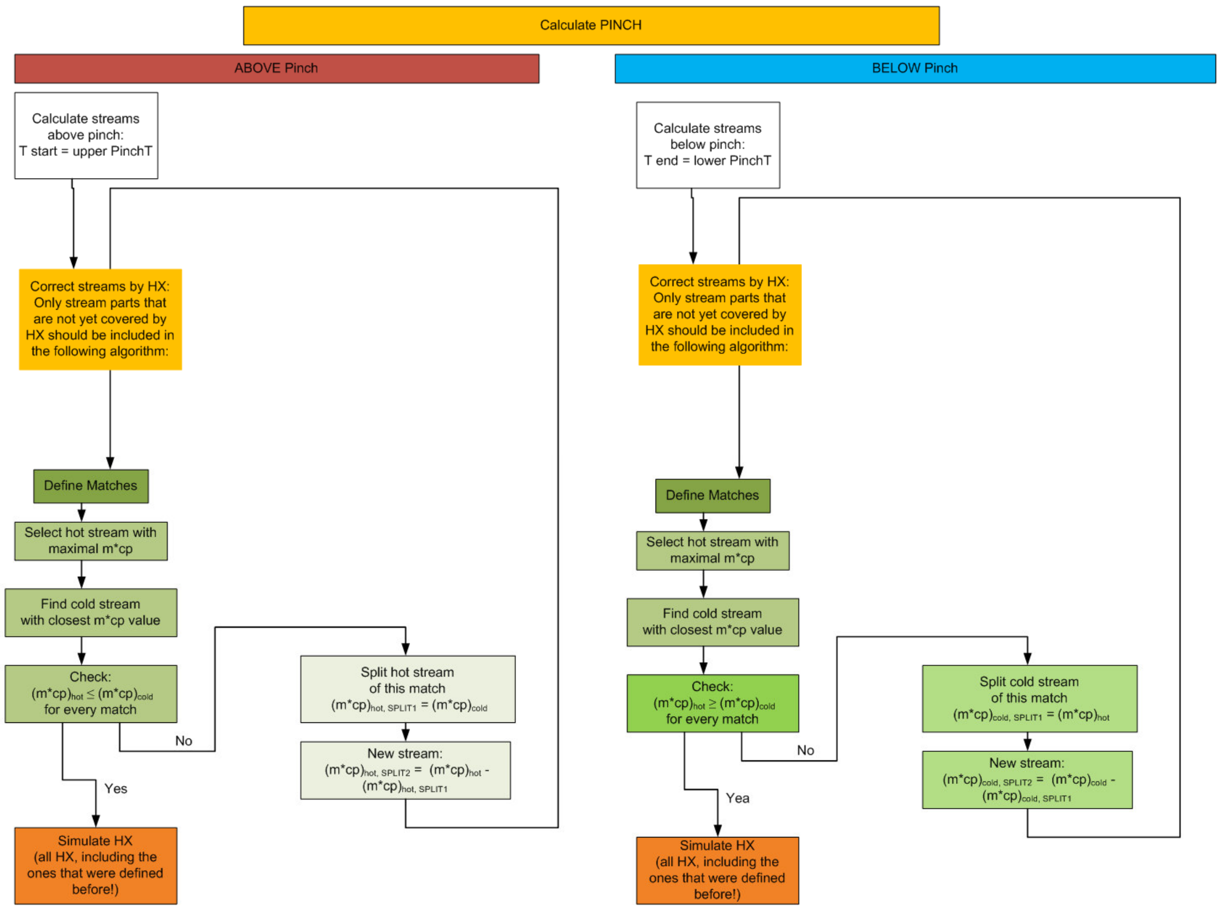
General Criteria for a HEX network:

- ✓ Use of heat at a certain temperature level for heating other streams to a similar temperature level
- ✓ Power of heat exchange
- ✓ Total transferable energy over the heat exchangers
- ✓ Heat integration within the same process should be given priority - direct use of waste heat
- ✓ Use of heat that has to be cooled down by a cooling machine for heating up processes increase the energy savings by the heat exchange, as the external energy supply of the heat source and the heat sink can be saved
- ✓ Distance between the heat source (hot stream) and heat sink (cold stream)
- ✓ Practical issues, such as fouling factors, necessity of indirect heat exchange via a heat transfer media, temperature and pressure aspects etc.
- ✓ Investment costs and saved energy costs

Step 7.4: Pre-design of heat exchangers network

EINSTEIN‘s HX selection algorithm:

Based on Pinch Algorithm (Kemp et al., 2007):



Step 7.4: Pre-design of heat exchangers network

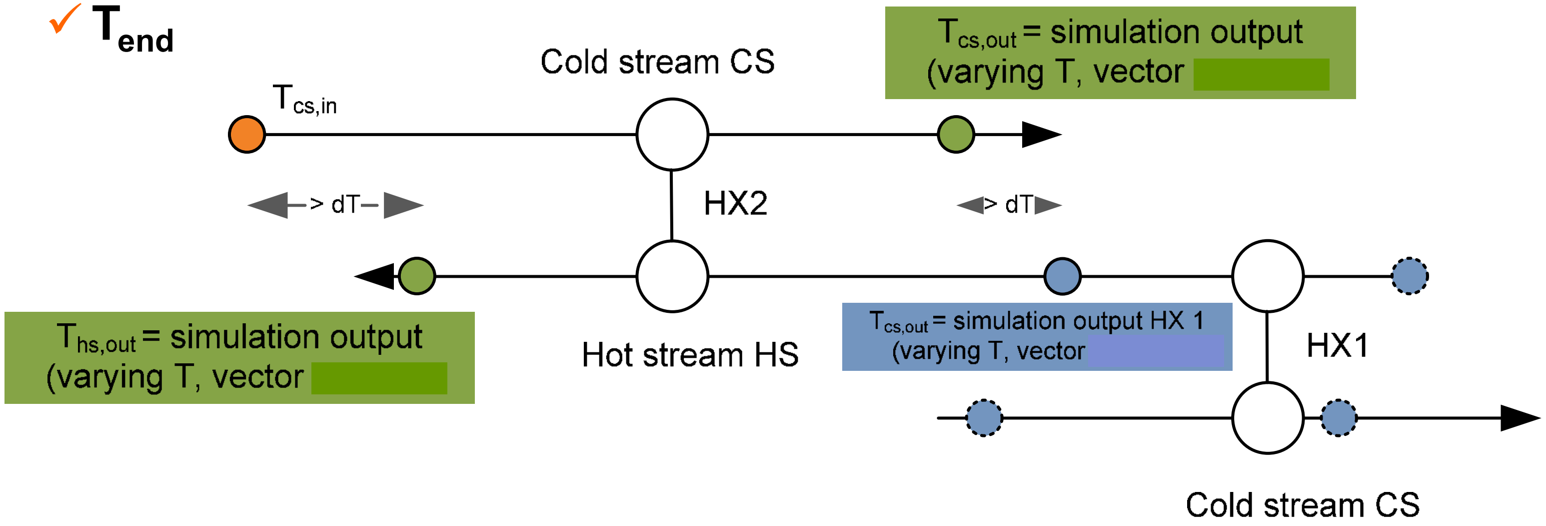
HX Simulation in EINSTEIN:

✓ **Start values for sinks and sources:**

- ✓ $Q_{\_t}$
- ✓ T_{start}
- ✓ T_{end}

✓ **Simulation results**

- ✓ Q_{HX_t}
- ✓ T_{inlet_t}
- ✓ T_{outlet_t}



Step 7.4: Pre-design of heat exchangers network

HX Simulation in EINSTEIN:

✓**Basic Equations:**

$$Q = m_{cs} * cp_{cs} * \Delta T_{cs} = m_{hs} * cp_{hs} * \Delta T_{hs}$$

$$\frac{\Delta T_{cs}}{\Delta T_{hs}} = \frac{m_{hs} * cp_{hs}}{m_{cs} * cp_{cs}}$$

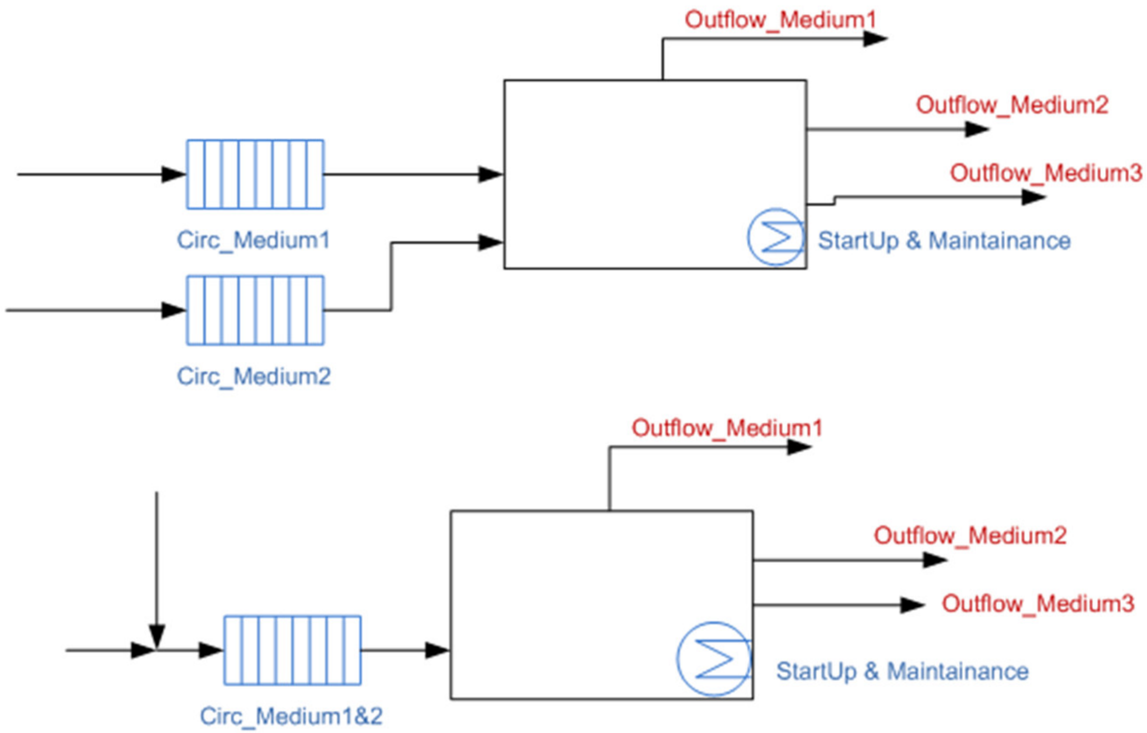
$$Q = U * A * \Delta T_{\log,hx}$$

$$\Delta T_{\log,hx} = \frac{(T_{hs,in} - T_{cs,out}) - (T_{hs,out} - T_{cs,in})}{\ln\left(\frac{(T_{hs,in} - T_{cs,out})}{(T_{hs,out} - T_{cs,in})}\right)}$$

Step 7.4: Pre-design of heat exchangers network

HX Simulation in EINSTEIN:

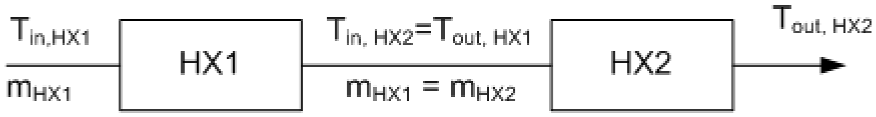
✓ **Several sources and sinks can be combined in one heat exchanger:**



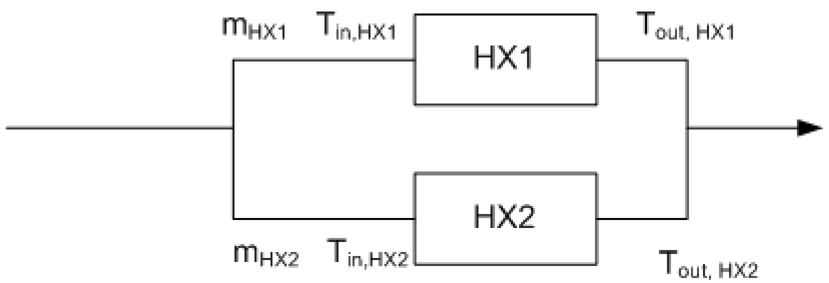
Step 7.4: Pre-design of heat exchangers network

Possible HX interconnections:

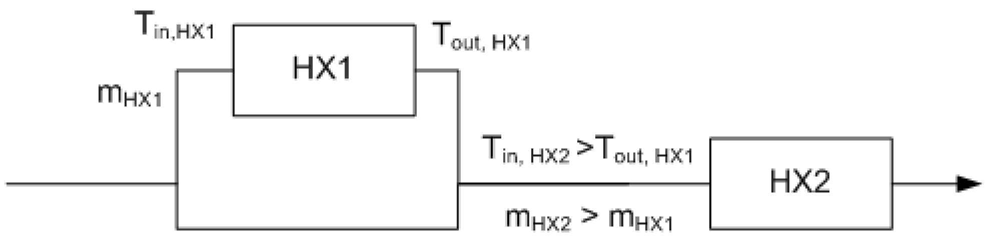
- ✓ **serial interconnection**



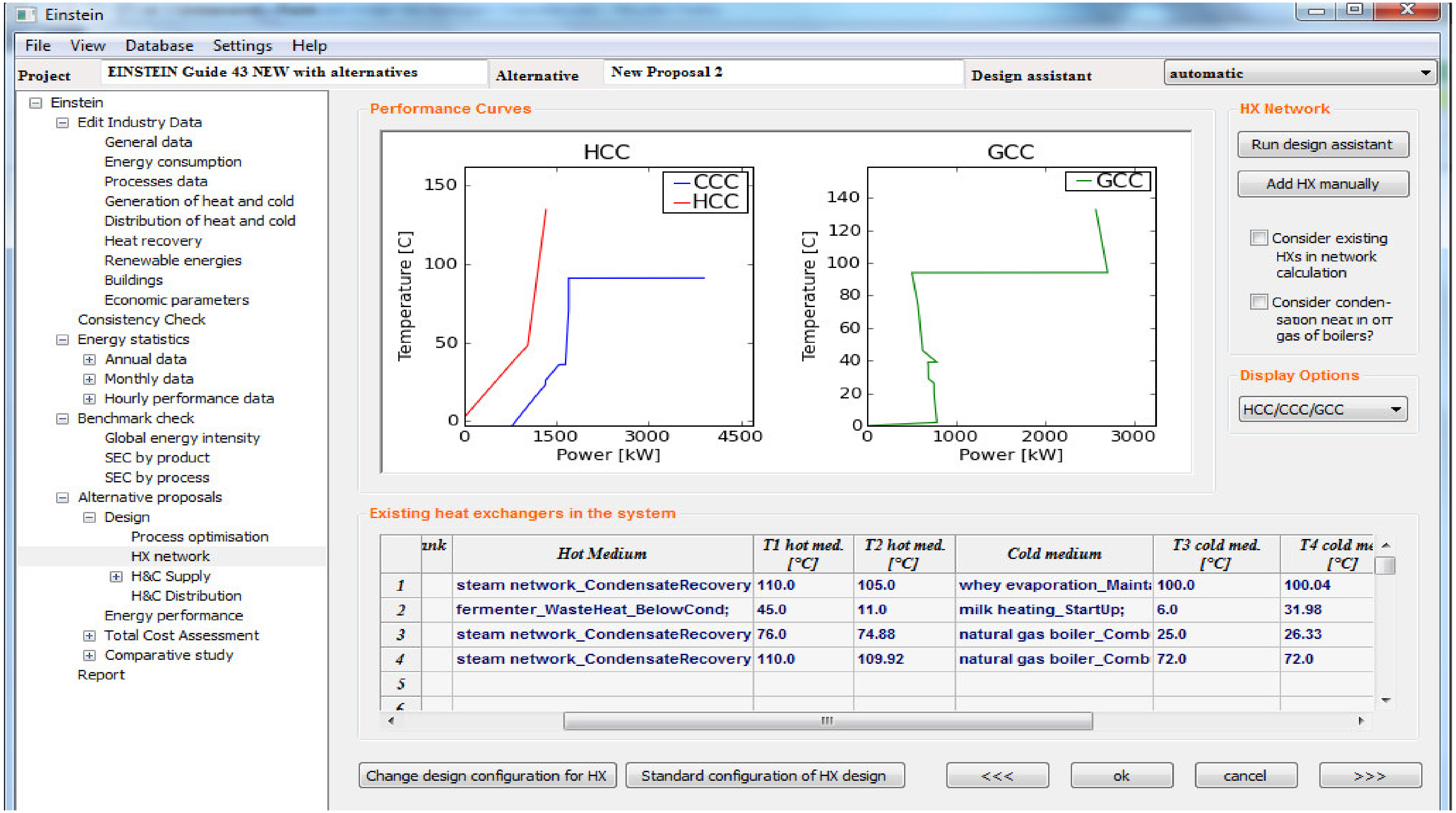
- ✓ **parallel interconnection**



- ✓ **serial interconnection with bypass**



Step 7.4: Pre-design of heat exchangers network



	Hot Medium	T1 hot med. [°C]	T2 hot med. [°C]	Cold medium	T3 cold med. [°C]	T4 cold me [°C]
1	steam network_CondensateRecovery	110.0	105.0	whey evaporation_Maint	100.0	100.04
2	fermenter_WasteHeat_BelowCond;	45.0	11.0	milk heating_StartUp;	6.0	31.98
3	steam network_CondensateRecovery	76.0	74.88	natural gas boiler_Comb	25.0	26.33
4	steam network_CondensateRecovery	110.0	109.92	natural gas boiler_Comb	72.0	72.0

Hot and cold composite curve, grand composite curve and proposed heat exchanger network

Step 7.4: Pre-design of heat exchangers network

Standard values for ΔT_{min} and the heat transfer coefficient α :

Physical state	ΔTmin [°C]	Heat transfer coefficient α [W/m²K]
Liquid	5	5.000
Gaseous	10	100
condensation	2,5	10.000

Heat exchanger types and overall heat transfer coefficients :

Heat exchange	Heat exchanger type chosen in EINSTEIN	Overall Heat transfer coefficient (material = stainless steel) α [W/m²K]	Average values given in VDI Heat Compendia [W/m²K]
Liquid - Liquid	Plate heat exchanger	2.143	1000 – 4000
Gaseous – liquid	Shell&tube	97	15-70
Condensation – liquid	Shell&tube	2724	500 – 4000
Gaseous – gaseous	Shell&tube	50	5-35
Condensation – gaseous	Shell&tube	99	20 - 60