UNIVERSITÀ DEGLI STUDI DI TRIESTE

Pinch Analysis

Course: INDUSTRIAL ENERGY MANAGEMENT [459MI]

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Objectives of the lesson:

- Understand the **fundamentals of the Pinch Analysis methodology** for identifying heat recovery possibilities in an energy system.
- Learn the main points about **Composite Curves** and **Problem Table**.
- Identify the **pinch point** in a **Heat Exchanger Network (HEN)**.

Pinch Analysis: definition

- Set of procedures aimed at defining the **Heat Exchanger Network (HEN)** in an energy system. Used also for other applications (e.g. heat recovery).

- **Industrial processes** consume **large** amounts of **thermal energy**.

Industrial processes

Hot streams that need to be cooled

Heating needs

Cooling needs

Cold streams that need to be heated

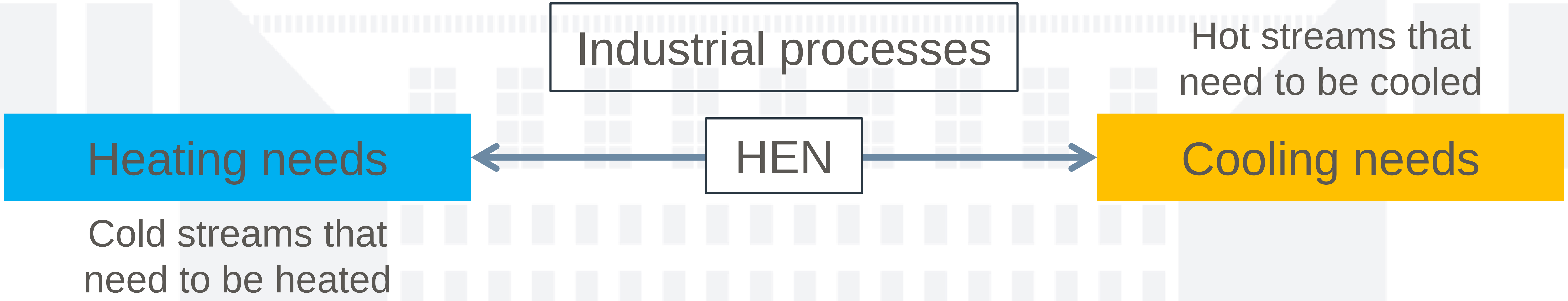
Pinch Analysis: definition

- Set of procedures aimed at defining the **Heat Exchanger Network (HEN)** in an energy system. Used also for other applications (e.g. heat recovery).
- **Industrial processes** consume **large** amounts of **thermal energy**.

Pinch Analysis: definition

- Set of procedures aimed at defining the **Heat Exchanger Network (HEN)** in an energy system. Used also for other applications (e.g. heat recovery).

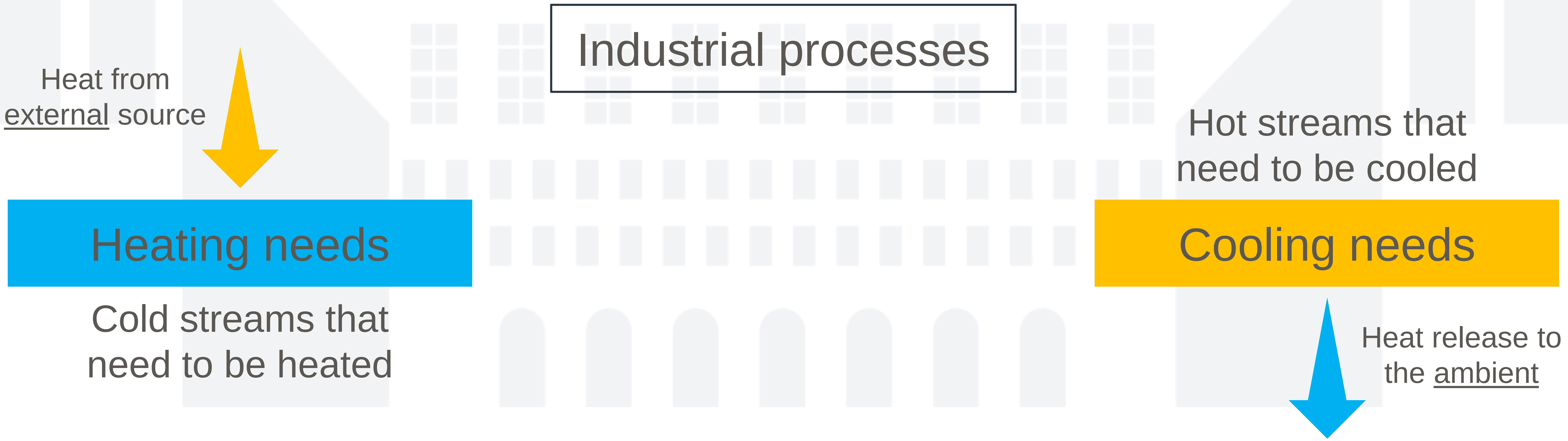
- **Industrial processes** consume **large** amounts of **thermal energy**.



The more optimised the integration of hot and cold flows, the greater the energy savings in the overall system

Pinch Analysis: definition

- Pinch analysis helps **minimize external utilities** by **maximizing heat recovery**
- Primary goal → minimize **external interactions**



Pinch Analysis: definition

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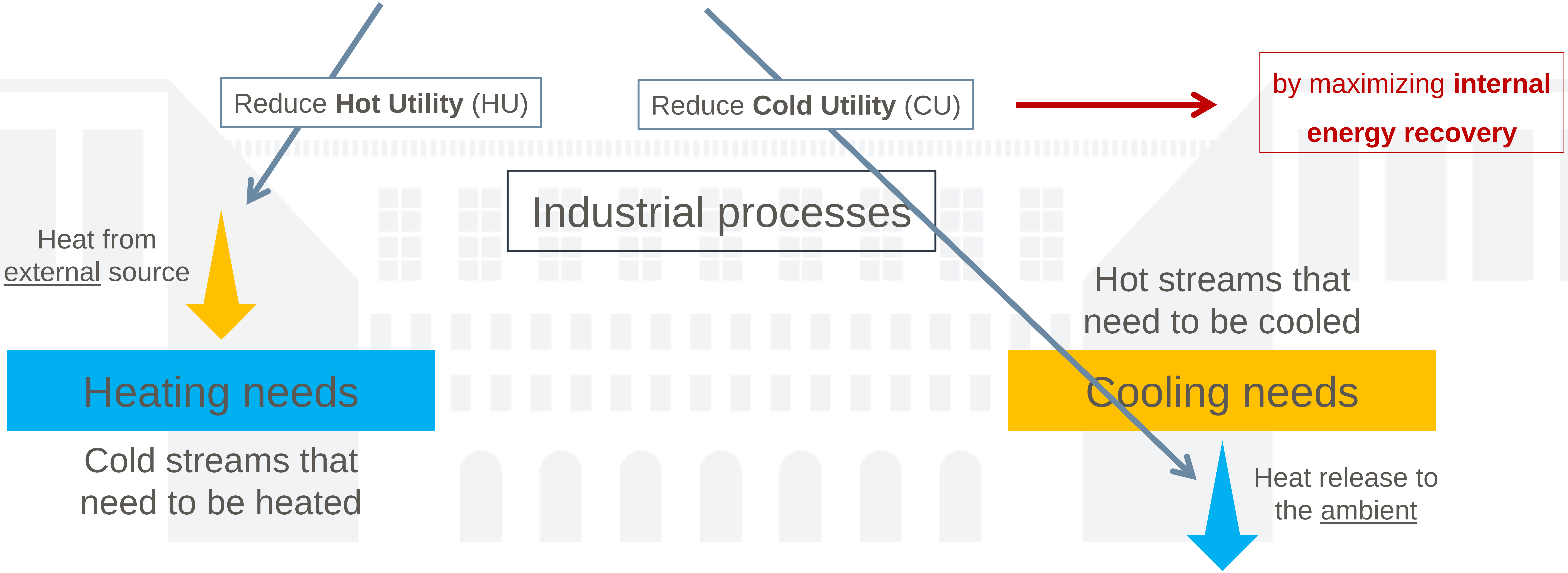


Pinch Analysis: definition

- Pinch Analysis can be seen as a practical application of **Second-Law (Exergy) Analysis** for heat exchange processes.

- It aims to **minimize exergy destruction** due to heat transfer irreversibilities.

- **Benefits:**

Lower fuel consumption ✓

Lower environmental impacts ✓

Pinch Analysis: definition

Main steps:

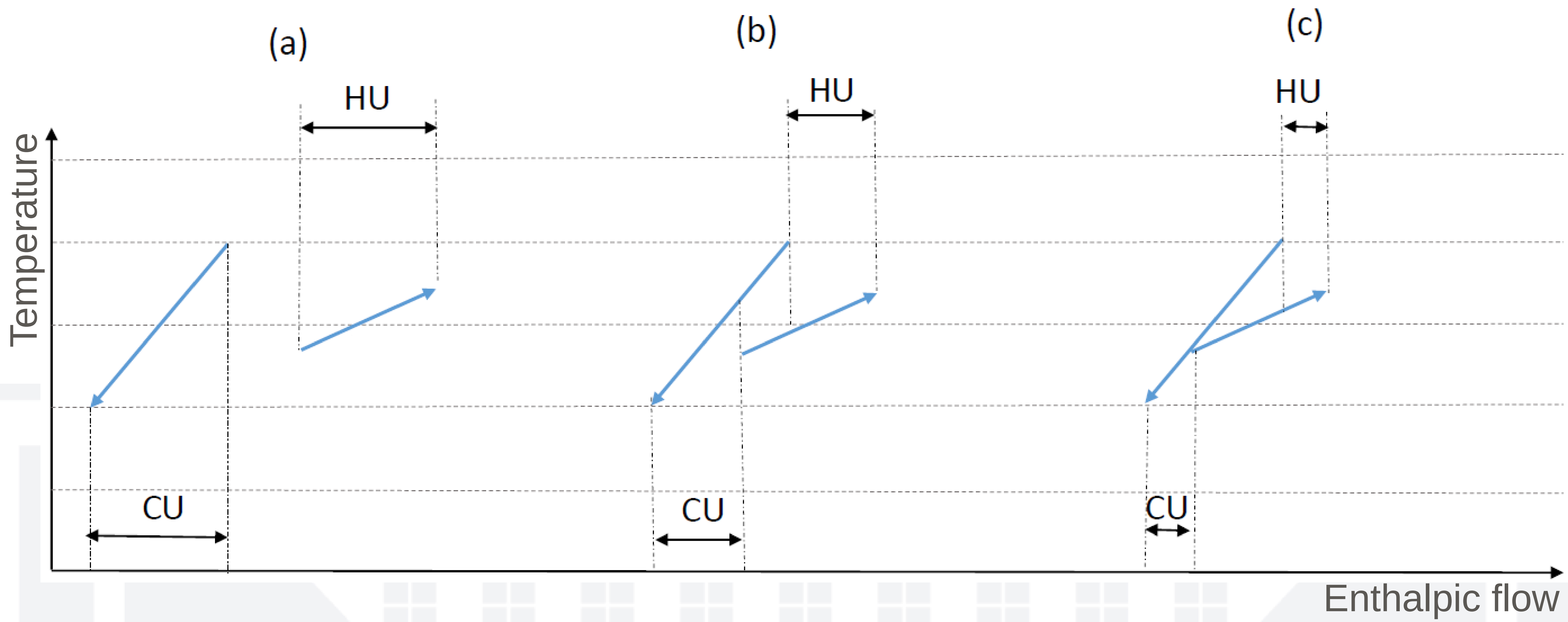
1. Identification of **hot and cold flows** in the system (considering that the thermodynamic data of each flux is already known)

2. Building the **composite curves**

3. Selection of **minimum temperature difference**

4. Problem table

Heat transfer representation in the T-Δh diagram



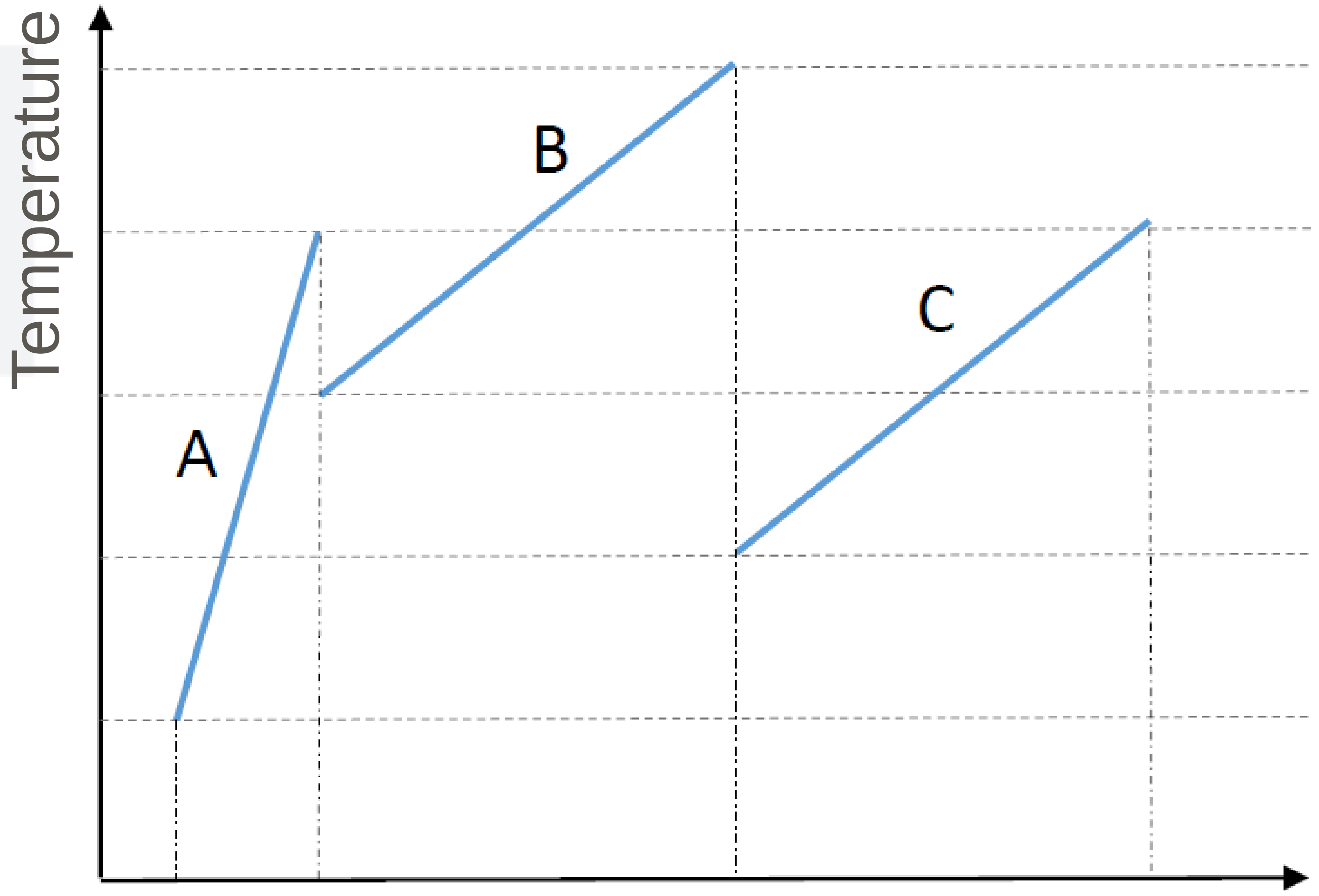
HU: Hot Utility

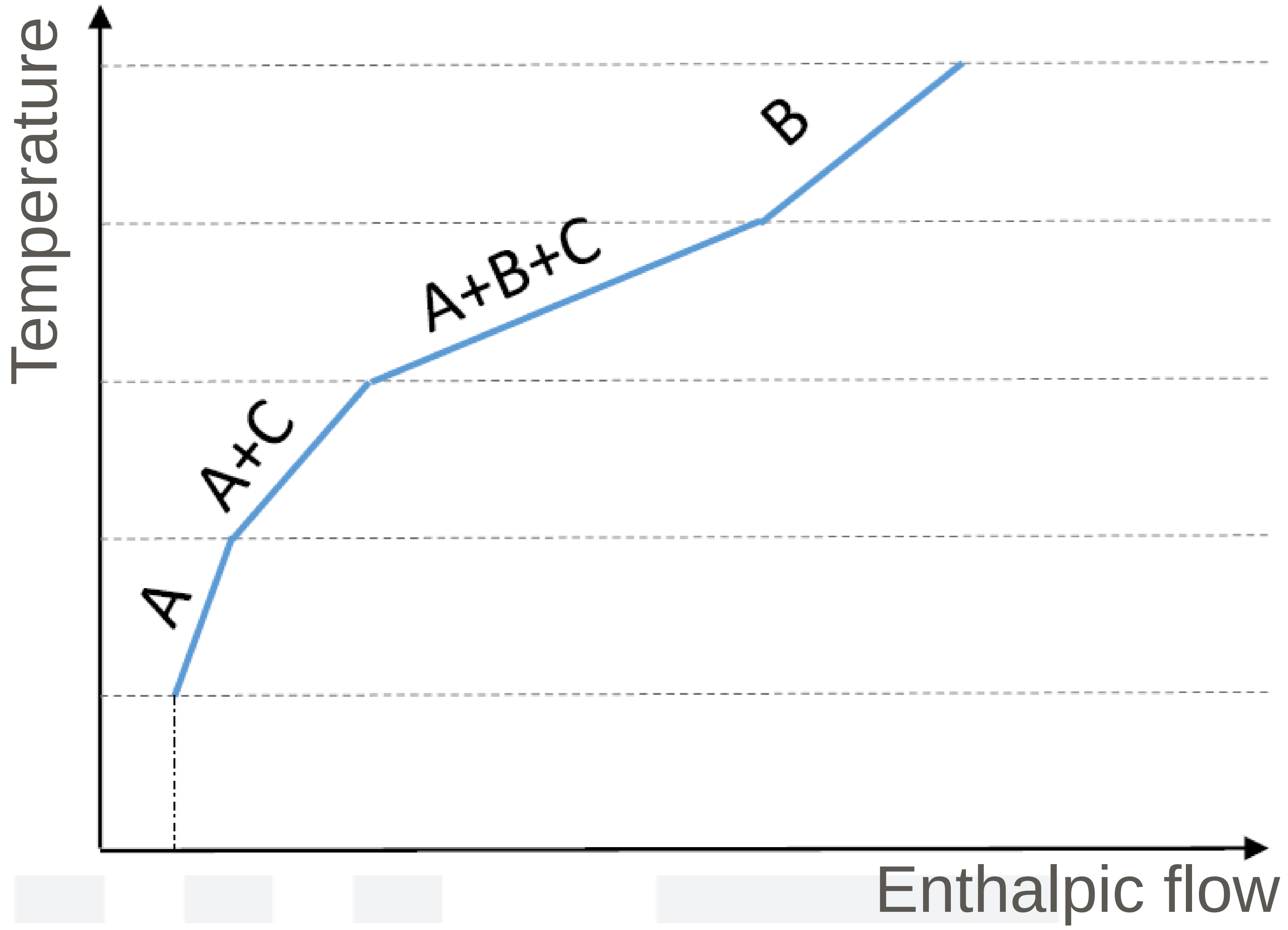
CU: Cold Utility

- **Case (a):** non-integrated flows, heat is fully supplied by HU and released to CU.
- **Case (b):** part of the energy released by the hot stream is taken by the cold stream. Wasted energy and energy from external sources are reduced.
- **Case (c):** maximum integration of flows, HU and CU are the minimum possible.

Graphical method: composite curves

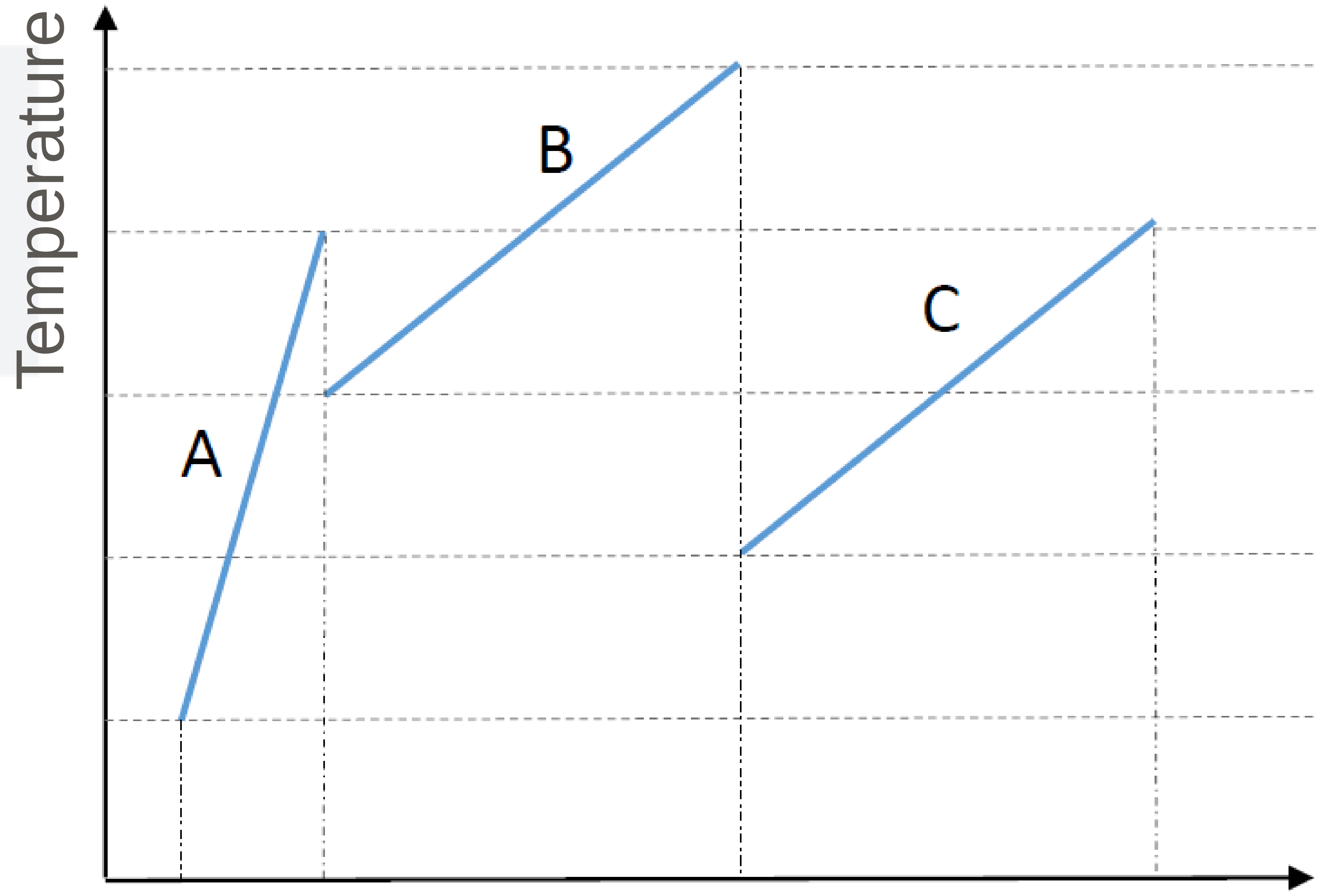
- Pinch Analysis finds its **most interesting applications** in cases where there are **several hot flows** to be cooled and **several cold flows** to be heated.
- The first step is to build the composite curves of the hot side (to be cooled) and the cold side (to be heated).

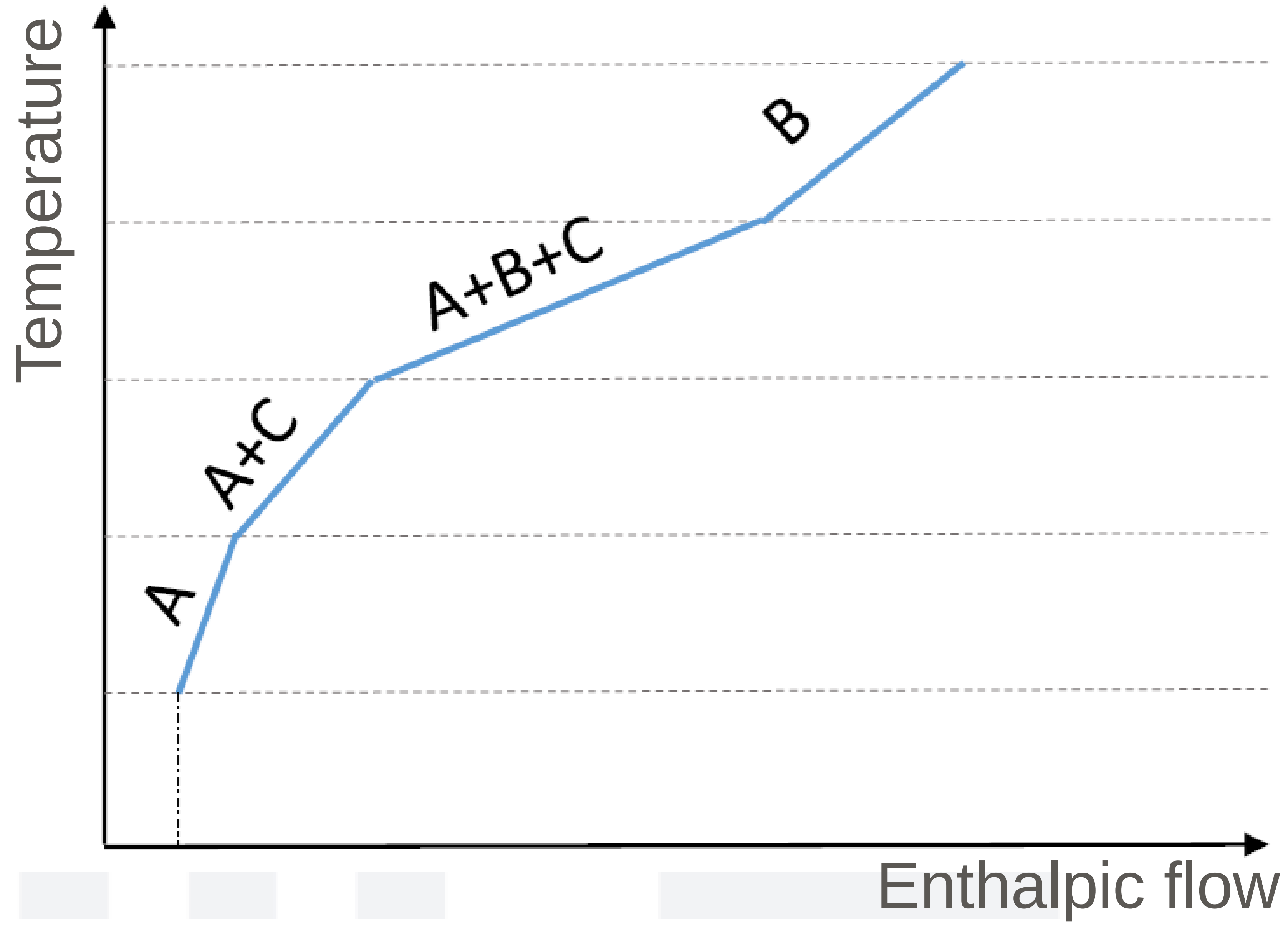




Graphical method: composite curves

- The **composite curve** represents the **heat exchange process** (cooling or heating) of a set of flows (hot or cold).
- For each **temperature interval**, the heat flow capacities are added together.
- The sum is multiplied by the temperature interval and the horizontal projection is the exchanged energy.



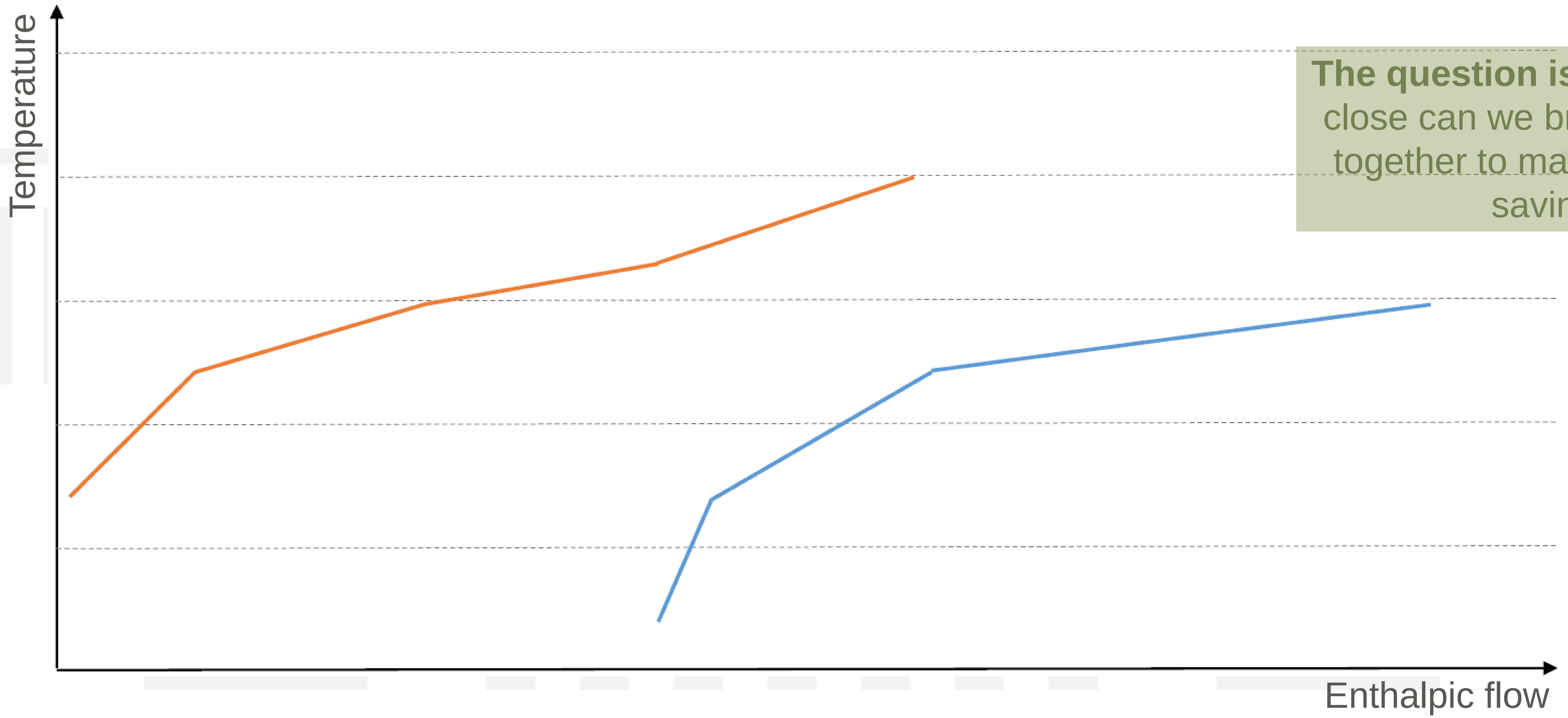


Slope → sum of the heat capacities of all heat flows involved in the temperature range considered

X-axis projection = total exchanged heat

Graphical method: composite curves

- In a **HEN** there will always be the **Cold Composite Curve (CCC)** relating to cold flows that need to be heated and the **Hot Composite Curve (HCC)** relating to hot flows that need to be cooled.



The question is: how and how close can we bring the curves together to maximize energy savings?

Graphical method: composite curves

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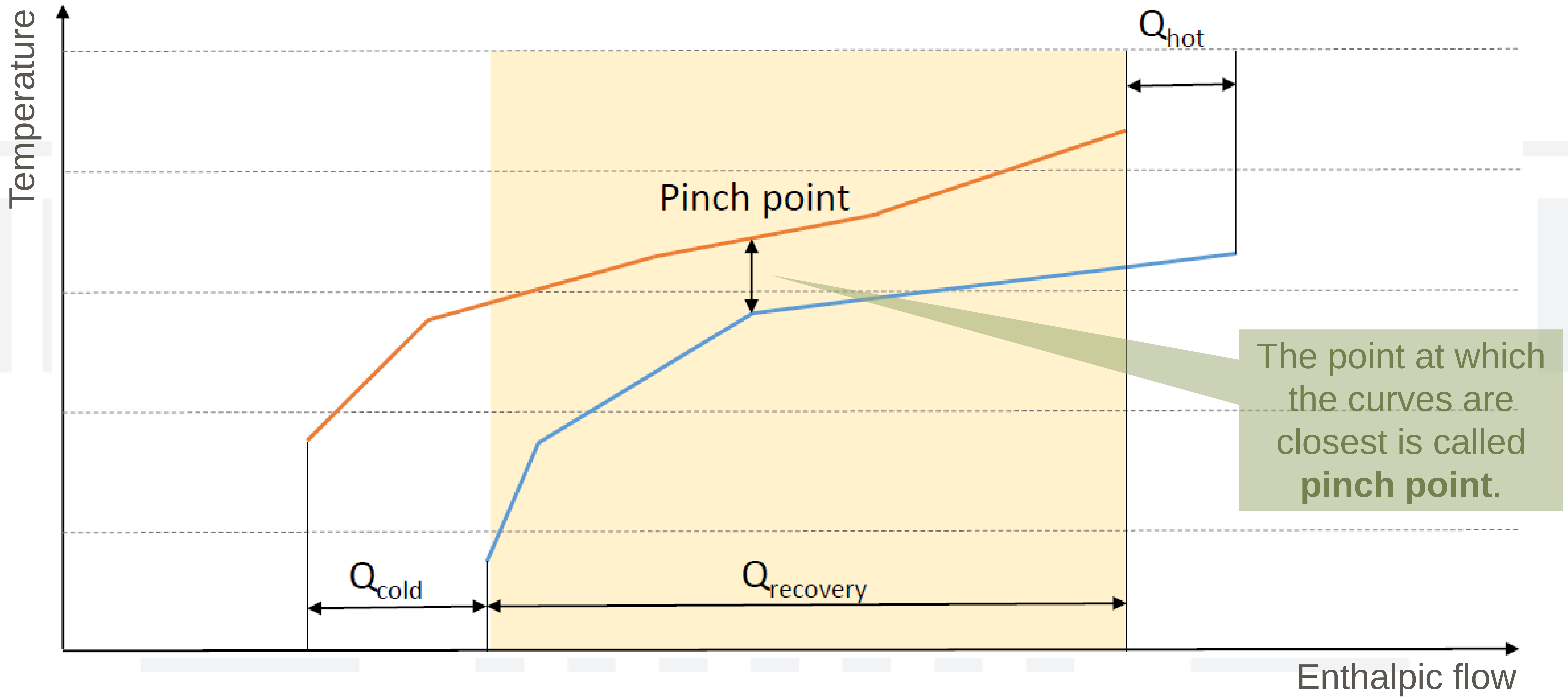

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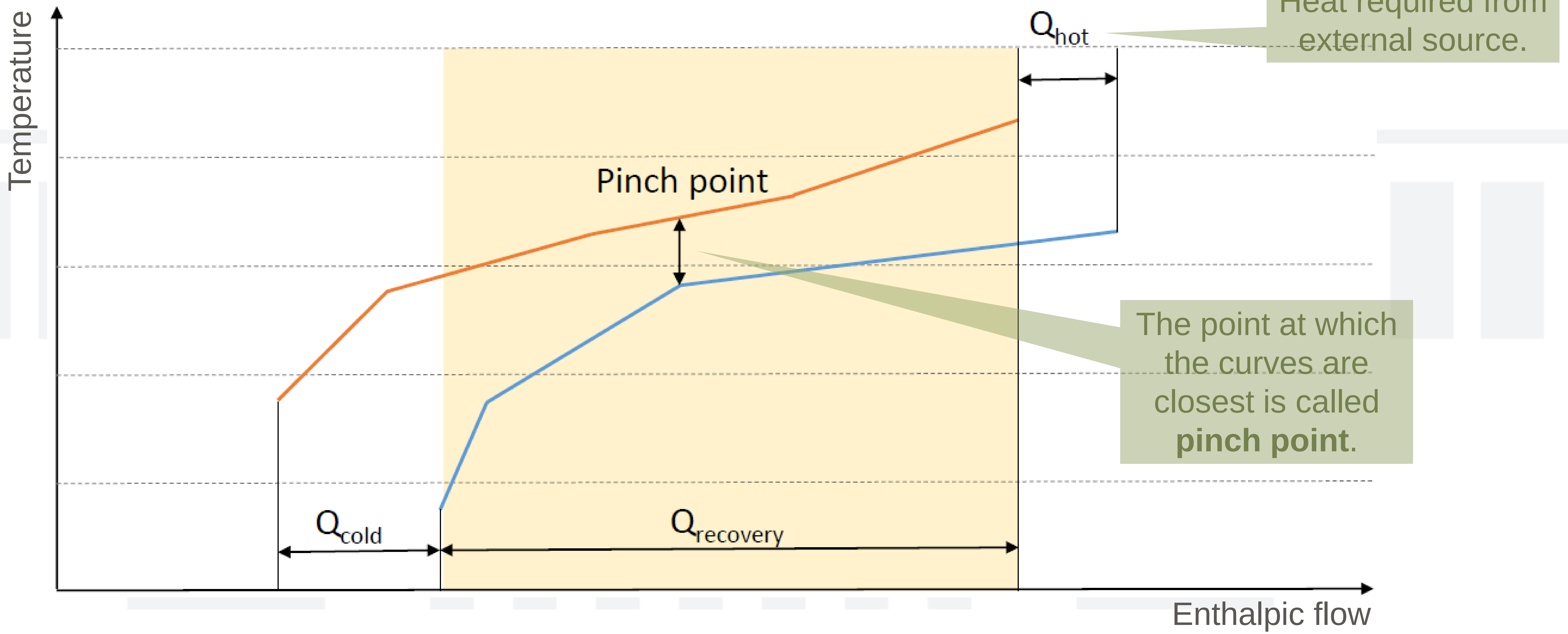

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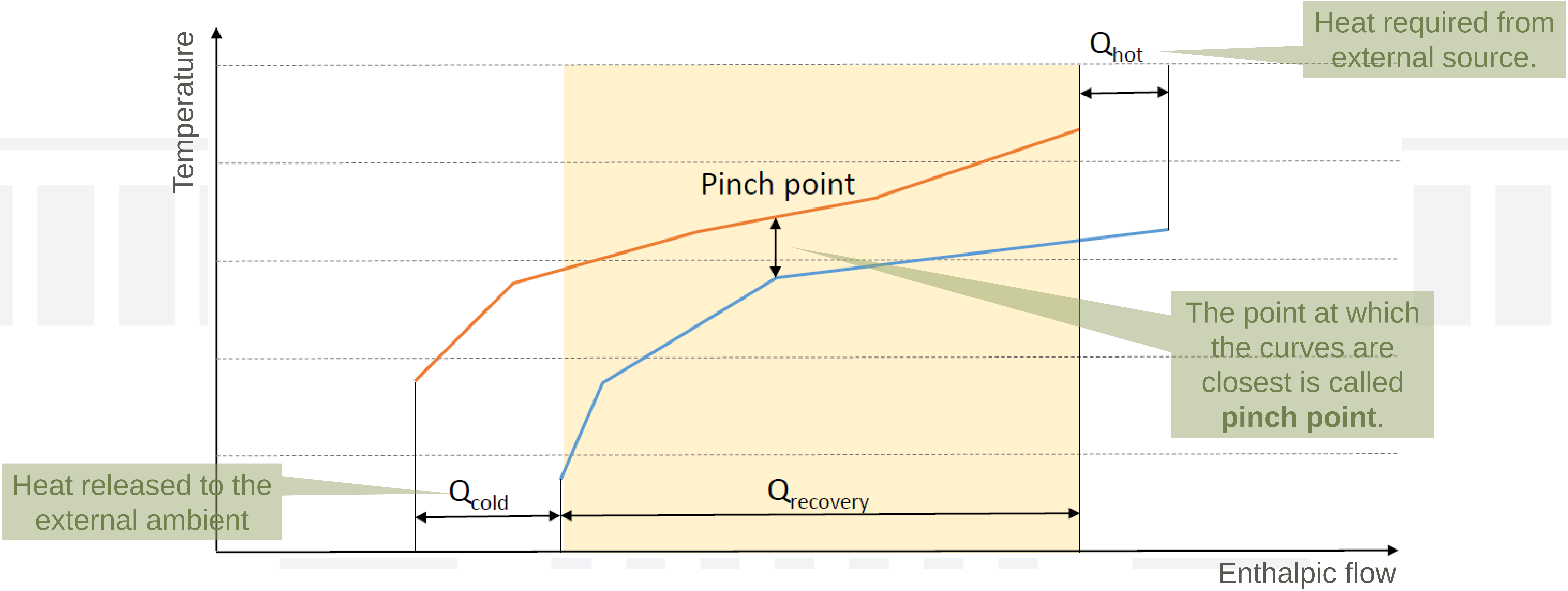

Graphical method: composite curves

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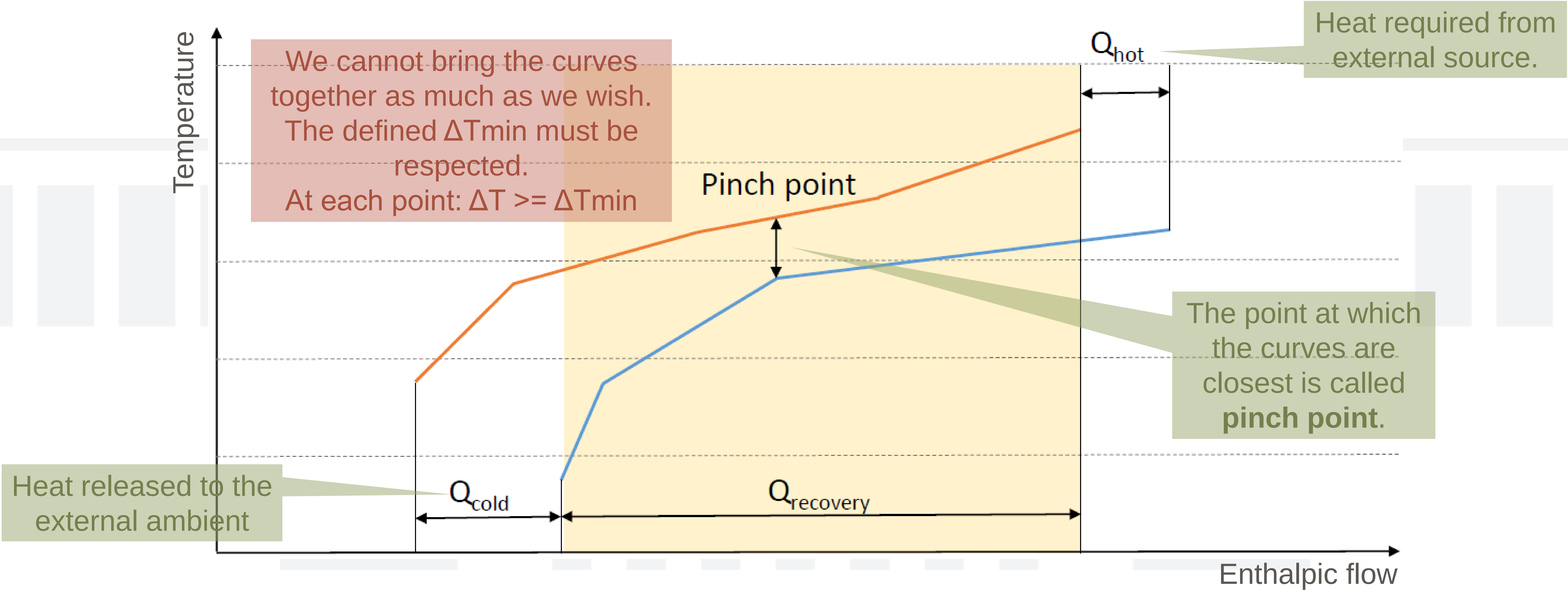

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Graphical method: composite curves

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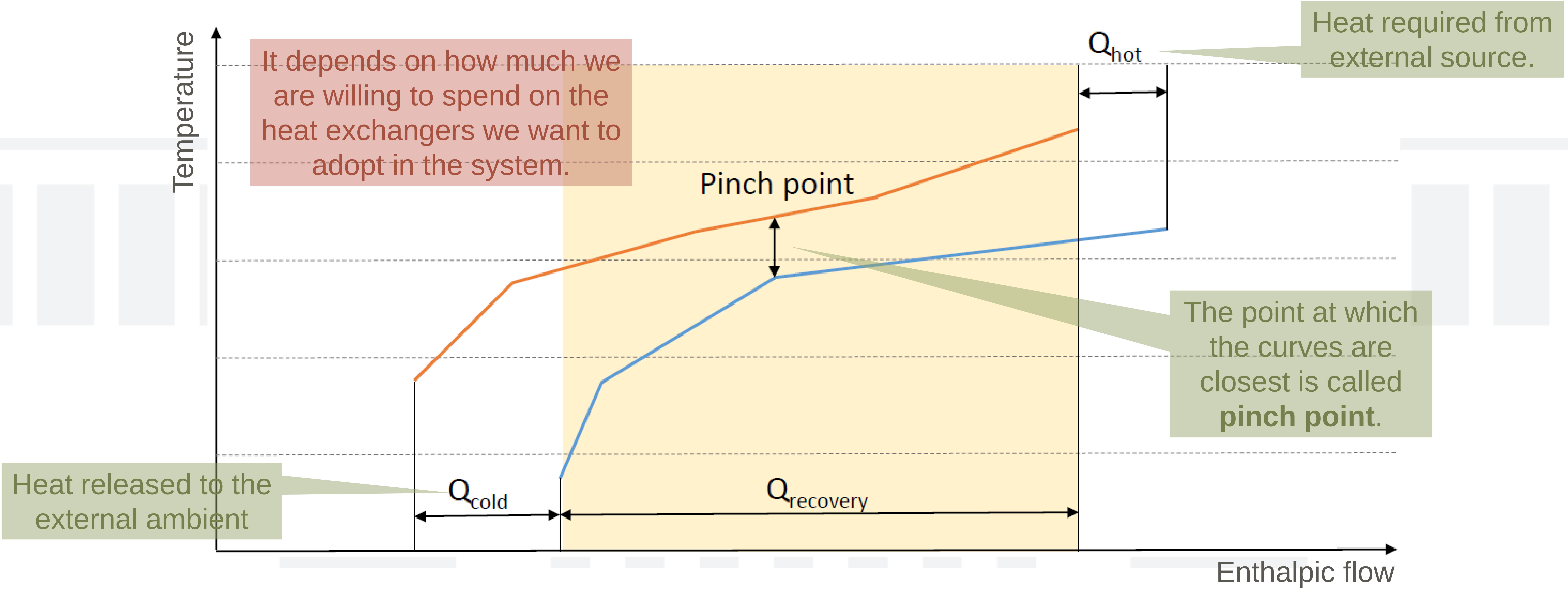
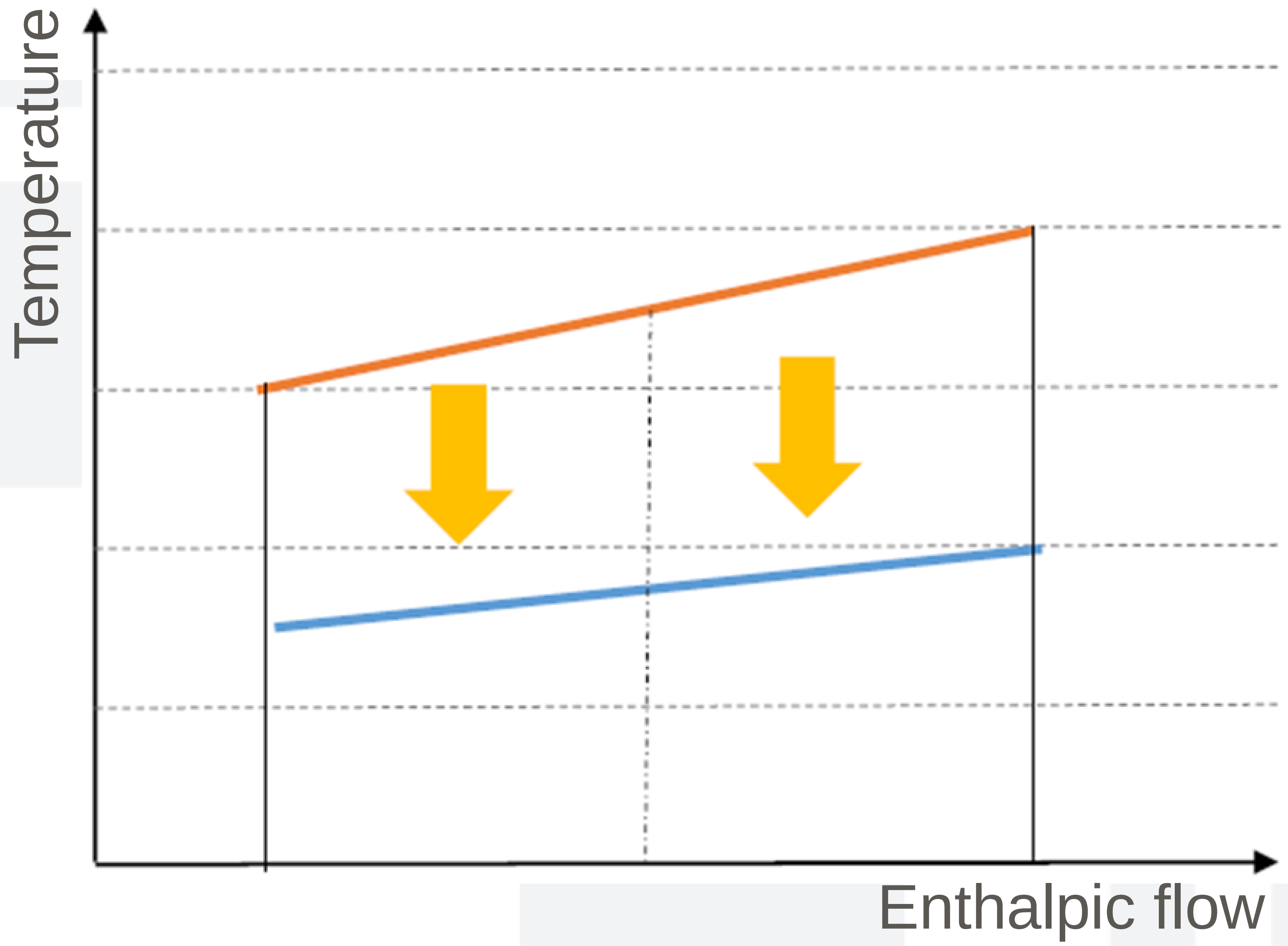
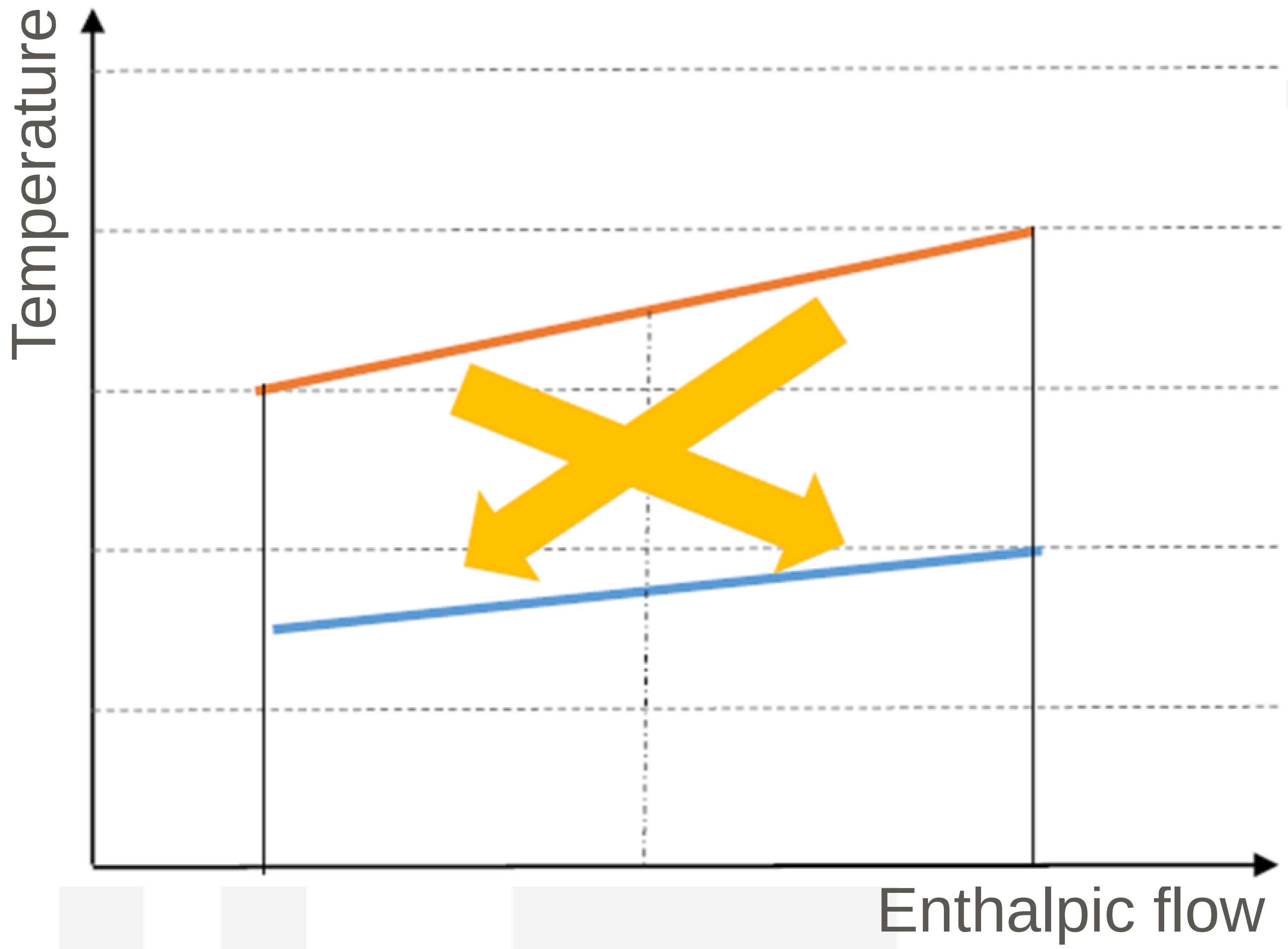


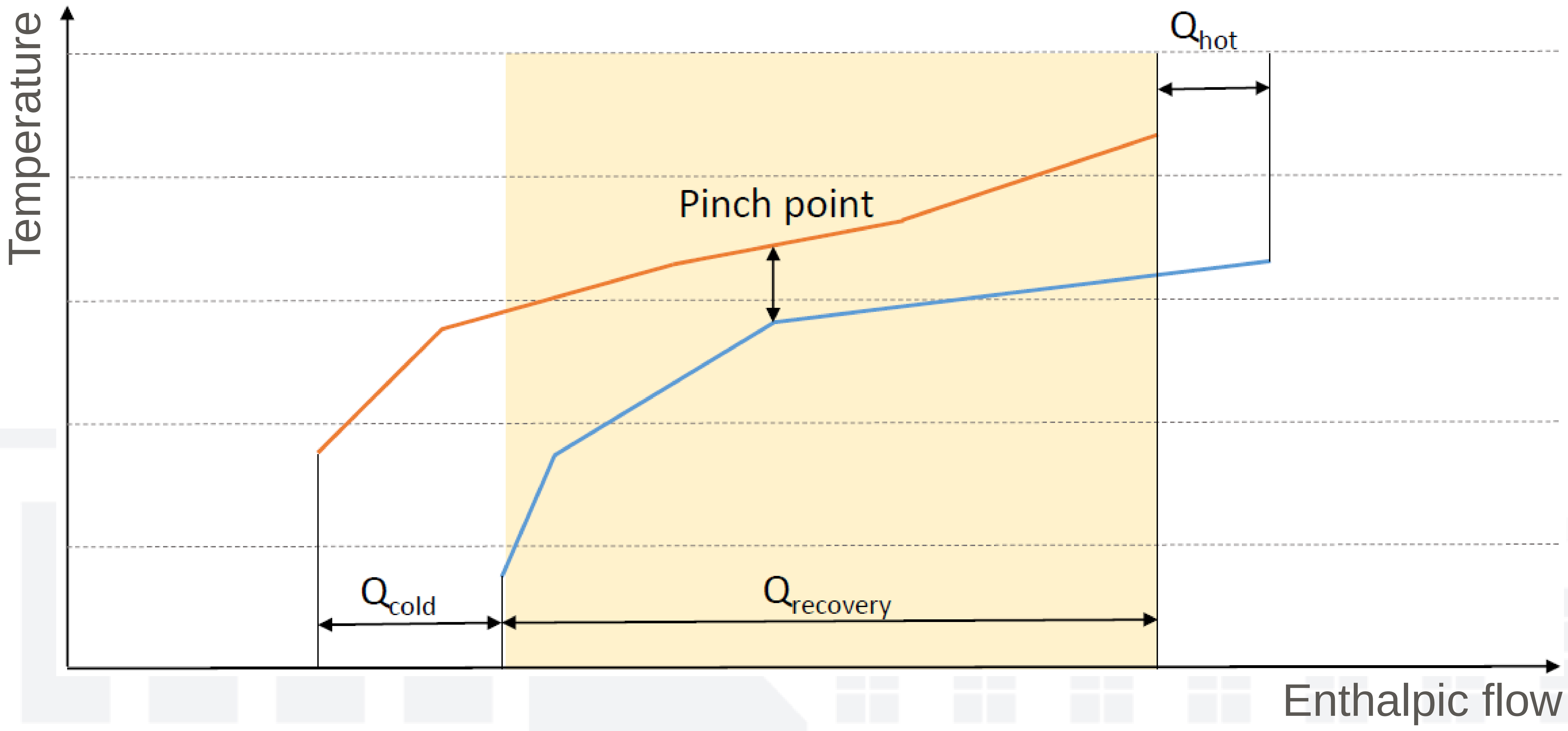
Graphical method: composite curves

- The composite curves **do not give any indication of how the heat exchange takes place** in each section.
- The feasibility constraint is only related to the chosen ΔTmin, which must be respected at each point.



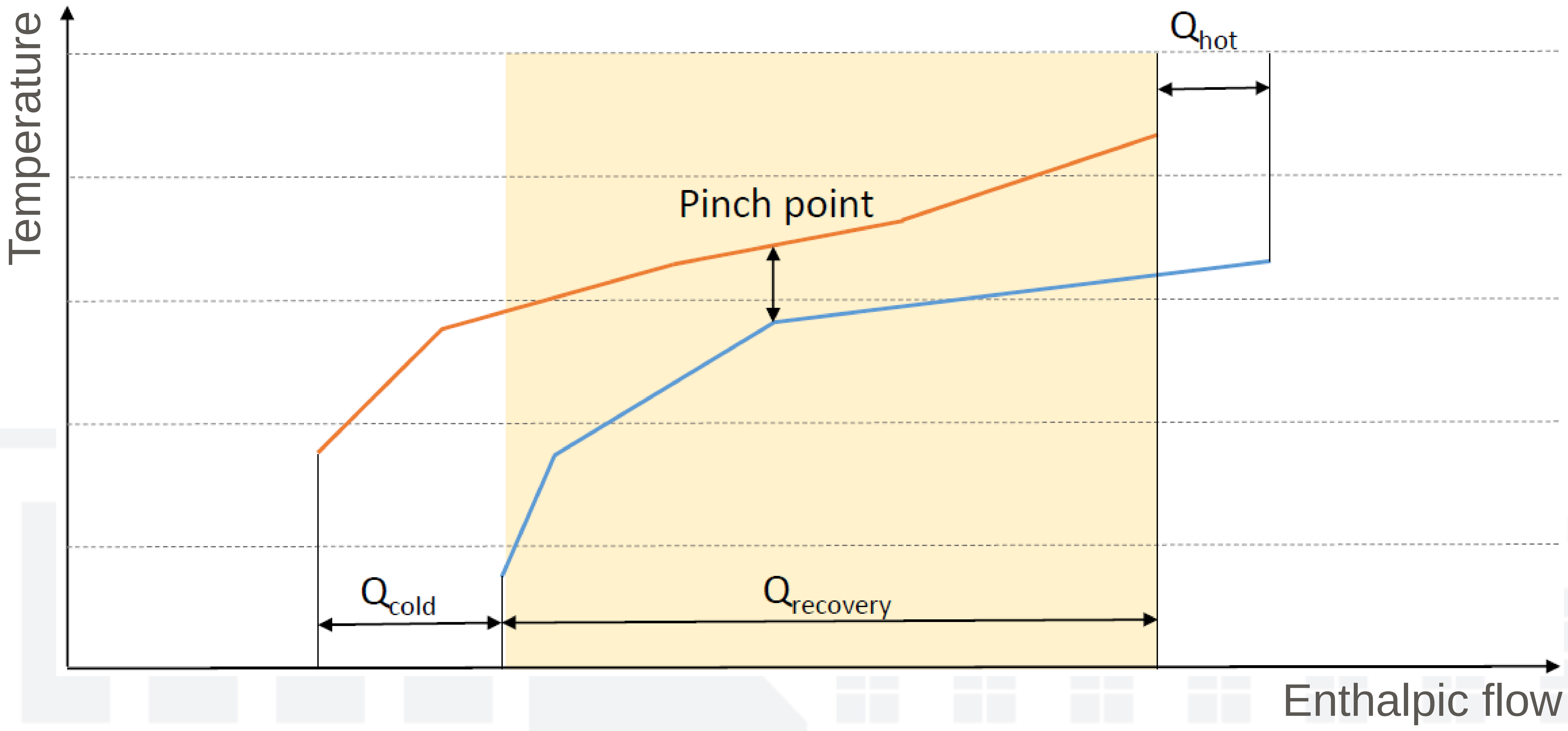


Graphical method: composite curves



- If the **minimum temperature difference** between the composite curves is **less than ΔTmin**, the heat exchange is **not feasible**.

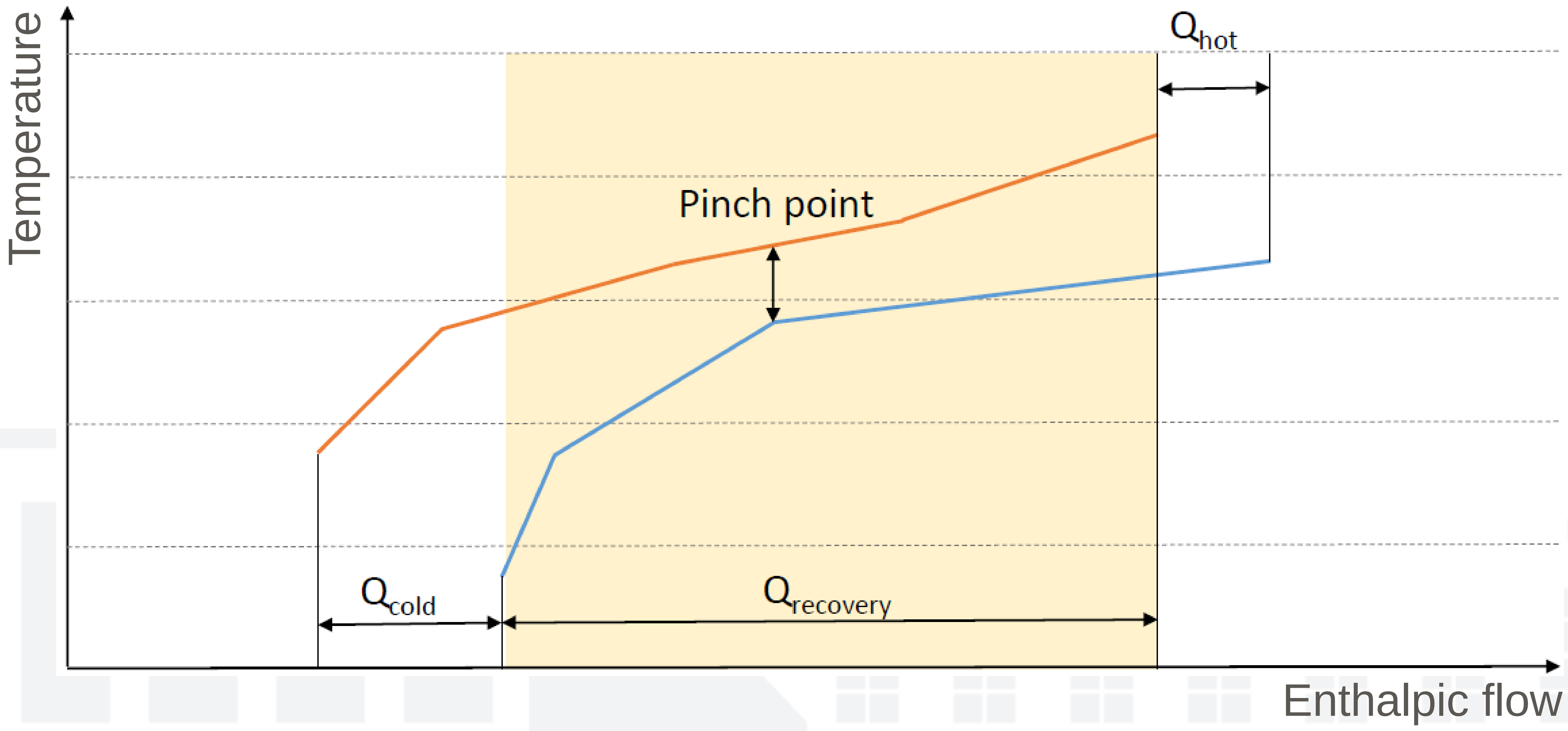
Graphical method: composite curves



- If the **minimum temperature difference** between the composite curves is **less than ΔTmin**, the heat exchange is **not feasible**.

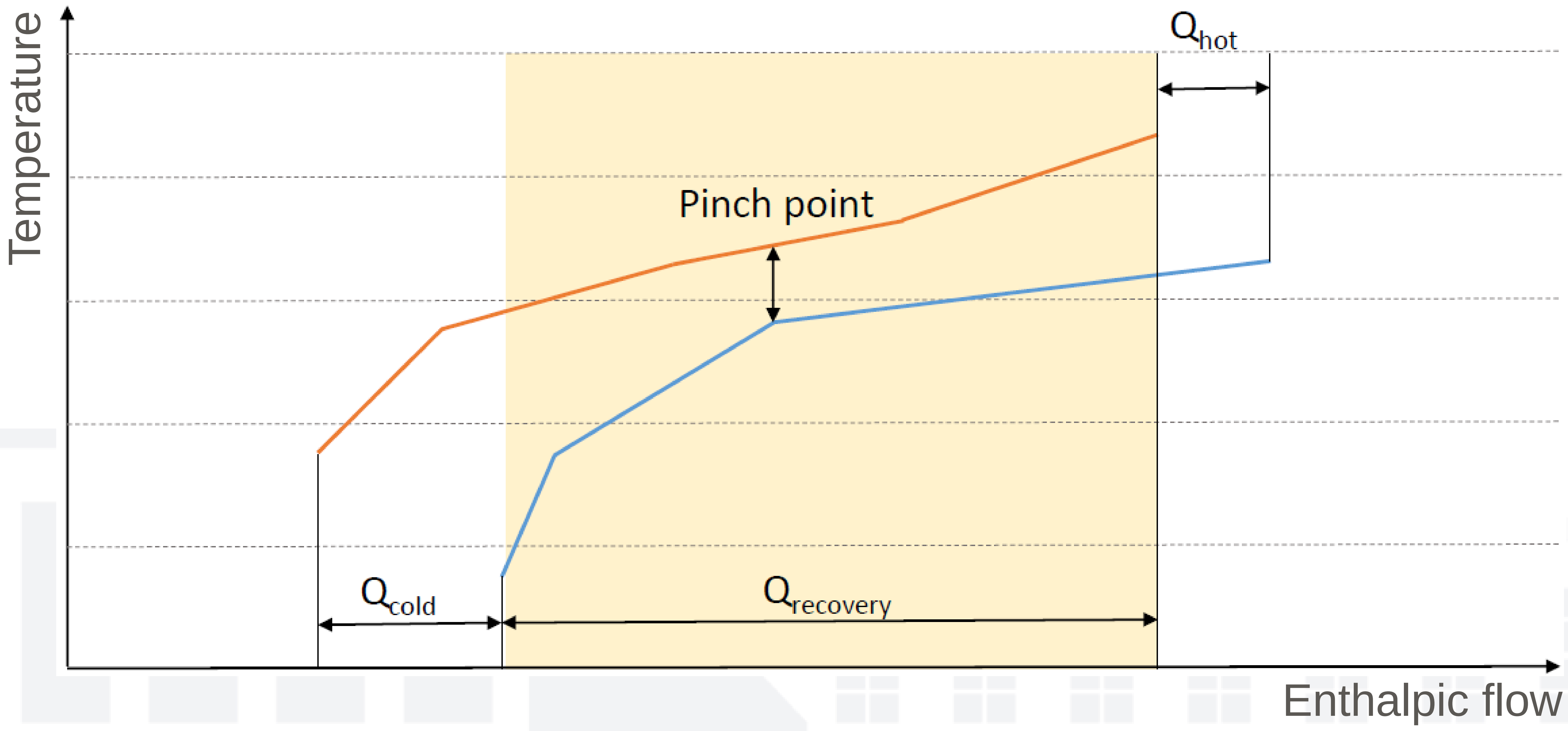
- This minimum ensures there is a **sufficient driving force** for heat to flow and helps avoid unrealistic or impractical designs.
- If the hot and cold curves come closer than ΔTmin, it means **the required exchanger would be infinitely large** (or impossible).

Graphical method: composite curves



- The **maximum heat recovery** is achieved when the **temperature** difference at the **pinch point** is equal to **ΔTmin** (ΔTmin = ΔTpp → maximum overlap of CCC and HCC).

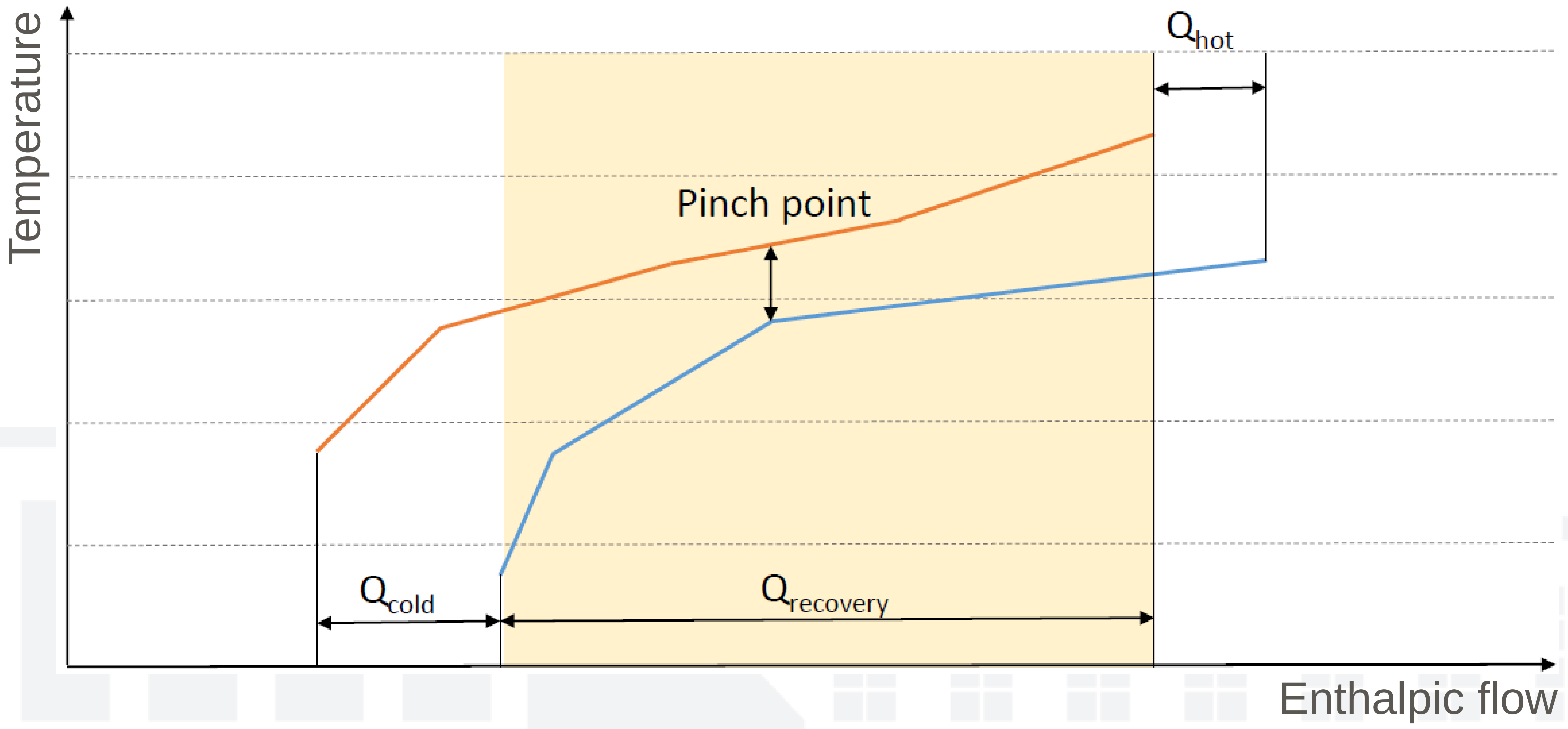
Graphical method: composite curves



➢ The **maximum heat recovery** is achieved when the **temperature** difference at the **pinch point** is equal to **ΔTmin** (ΔTmin = ΔTpp → maximum overlap of CCC and HCC).

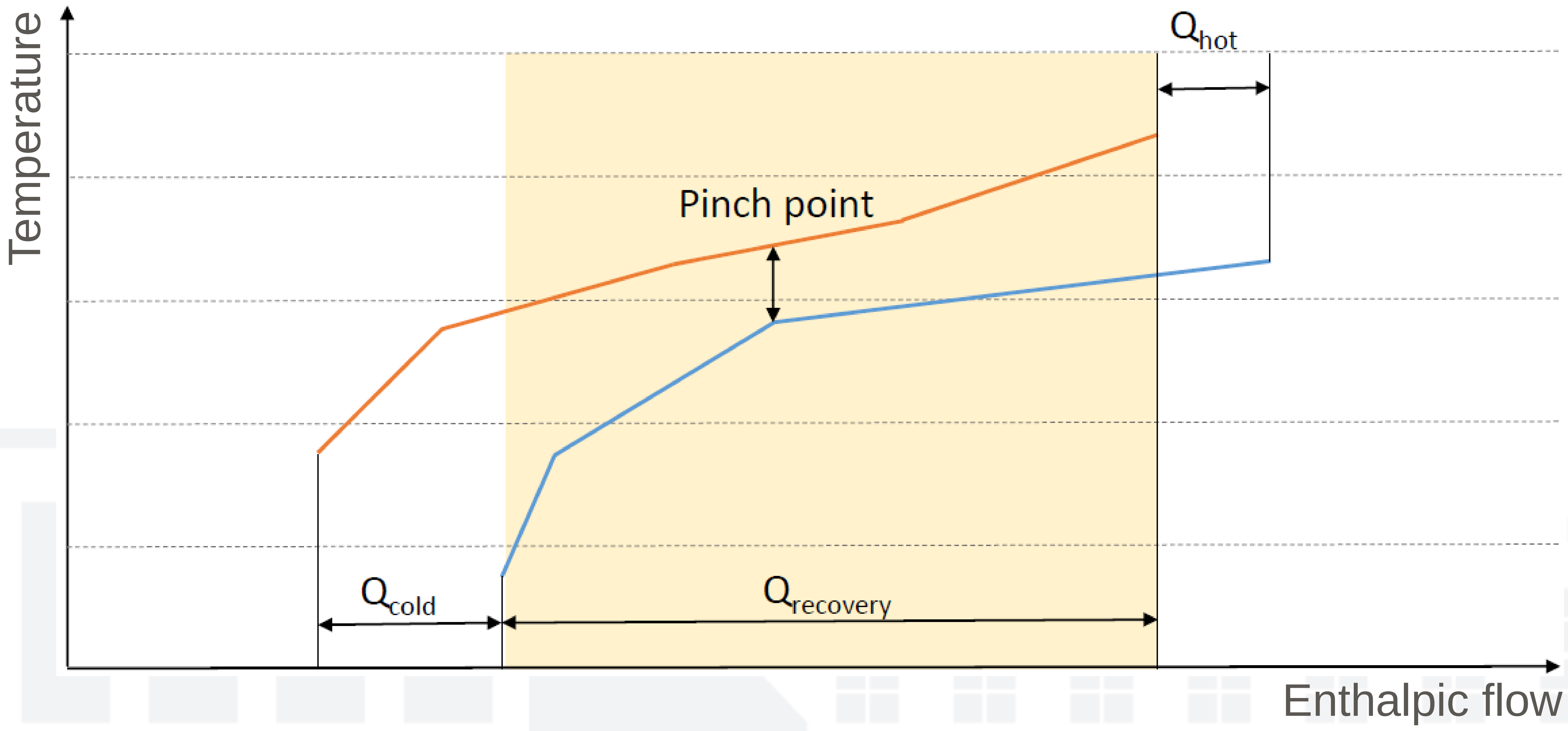
- The pinch point is where the **hot and cold composite curves are closest** (but not closer than ΔTmin).
- Maximized **internal heat recovery** and minimized **external heating and cooling**.
- The system is **reusing as much heat as physically possible**, without breaking the ΔTmin rule.

Graphical method: composite curves



- In the **optimal configuration**, Q_{cold} and Q_{hot} are **as low as possible**.

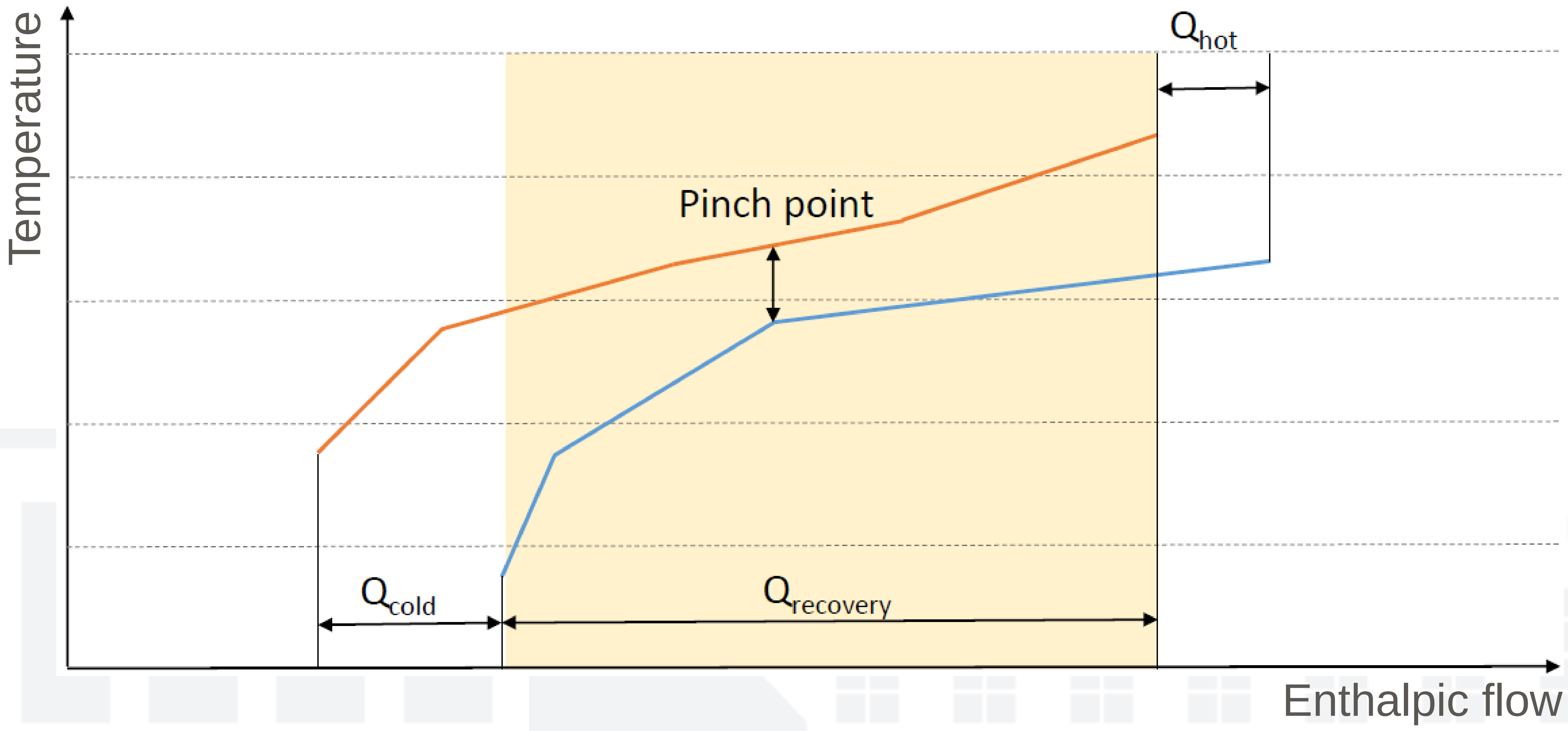
Graphical method: composite curves



- In the **optimal configuration**, Q_{cold} and Q_{hot} are **as low as possible**.

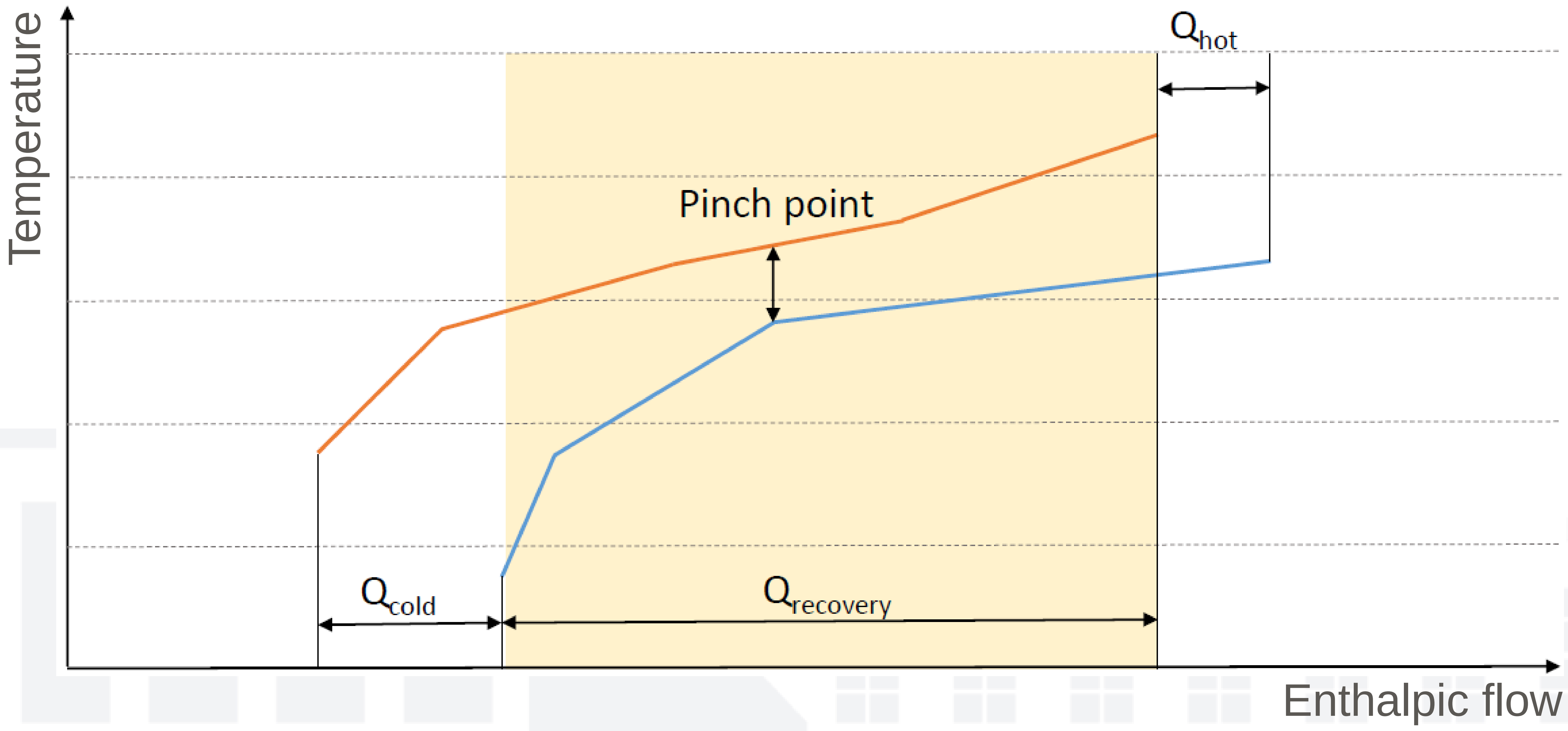
- The goal of pinch analysis is to **minimize both Q_{cold} and Q_{hot}** by transferring **as much heat as possible** within the system.

Graphical method: composite curves



- In the **optimal configuration**, the **heat exchange across the pinch point is zero**.

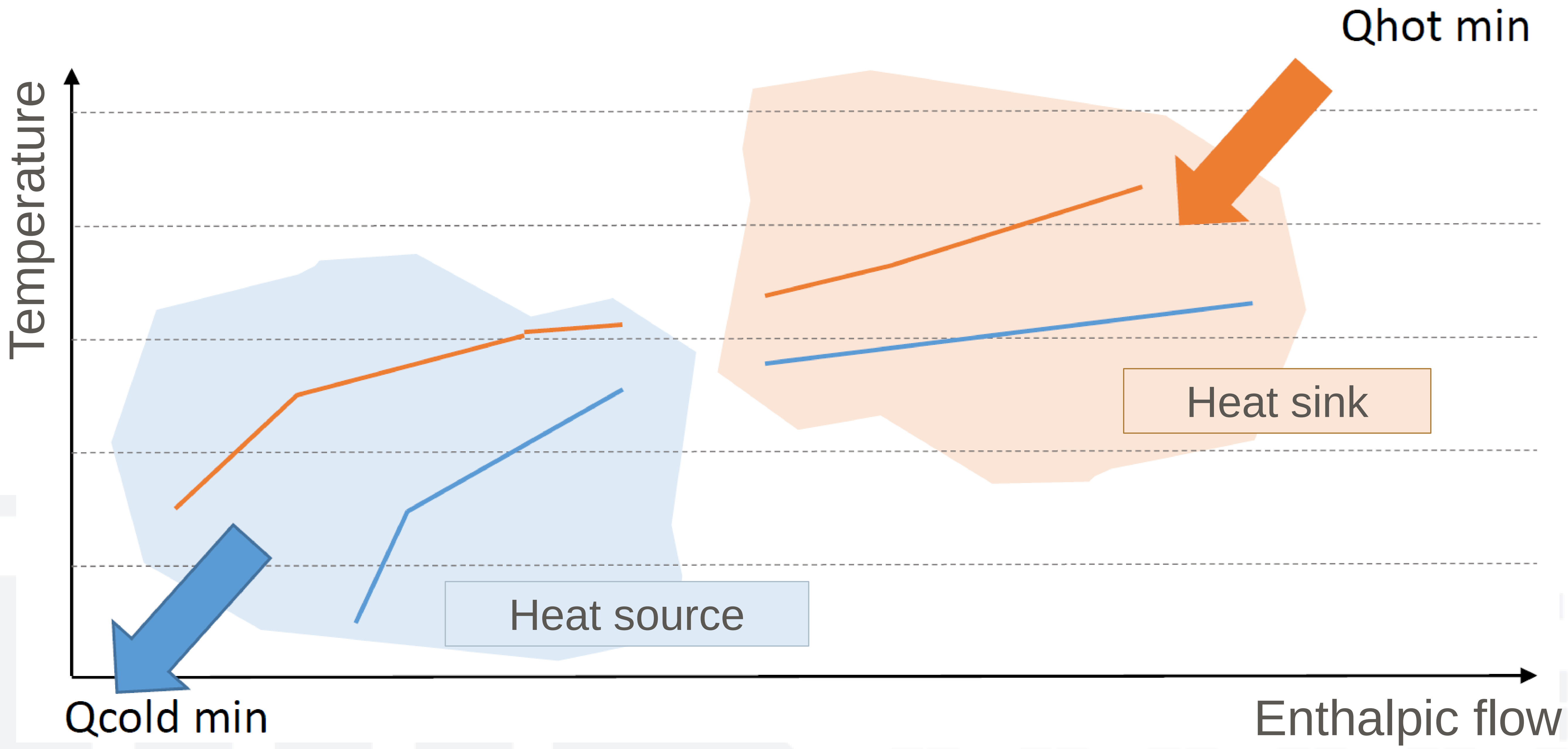
Graphical method: composite curves



- In the **optimal configuration**, the **heat exchange across the pinch point is zero**.

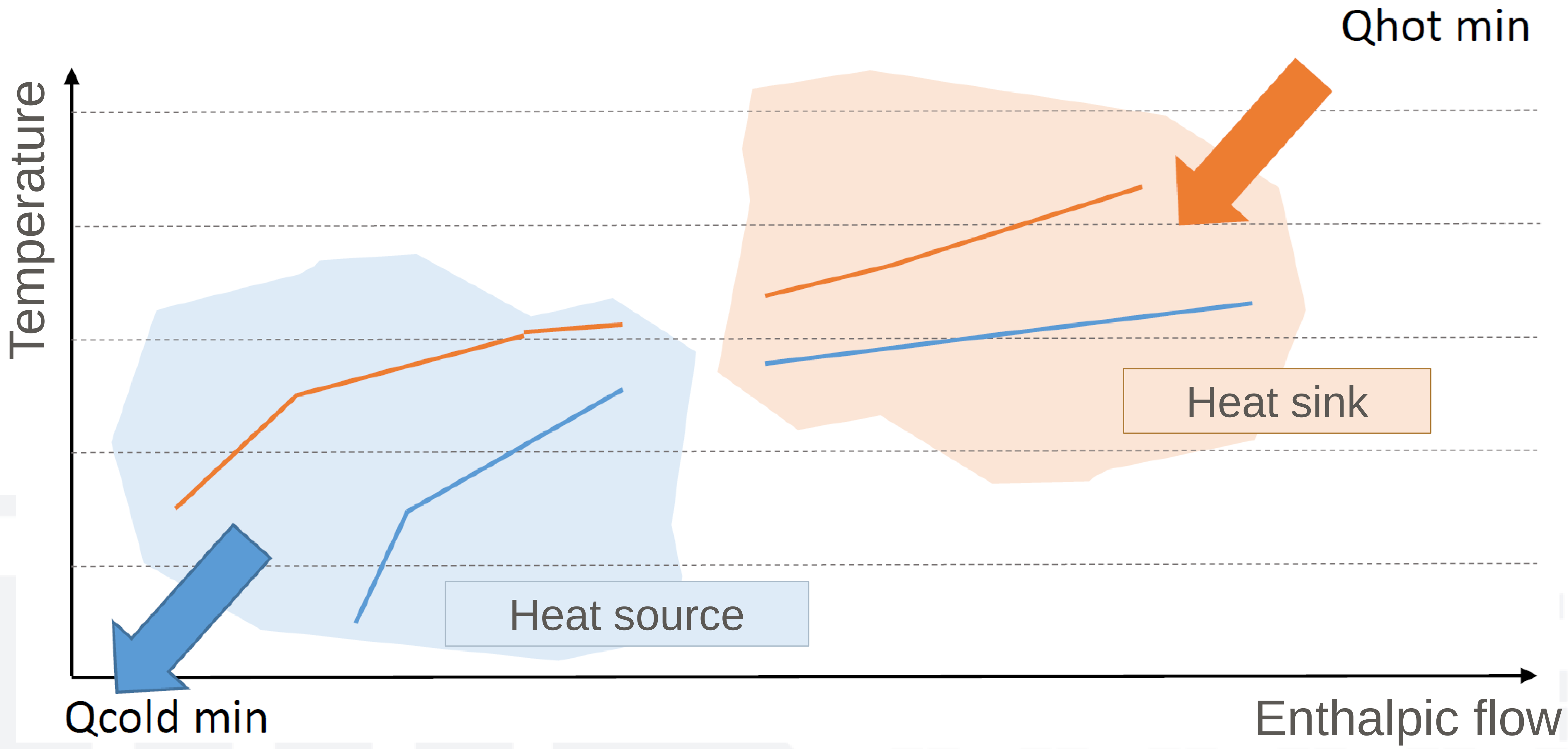
- We must not design heat exchangers that transfer **heat from hot streams above the pinch to cold streams below the pinch**.
- This would increase **both Q_{cold} and Q_{hot}** reducing efficiency.

Graphical method: composite curves



- If I exchanged heat through the PP (from right to left), then I would have to supply the same amount of heat that I exchanged through the PP from the outside. Not convenient.

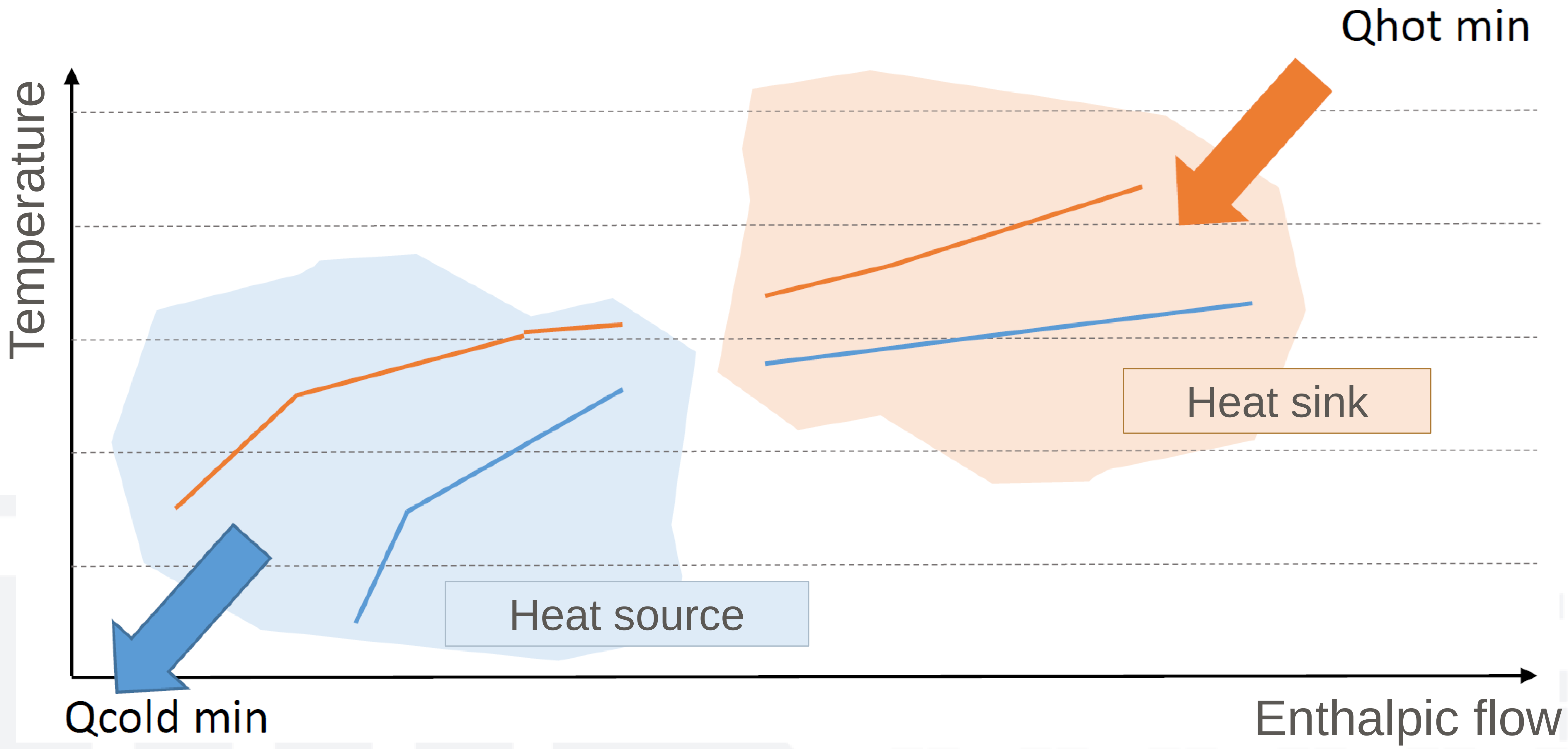
Graphical method: composite curves



➢ If I exchanged heat through the PP (from right to left), then I would have to supply the same amount of heat that I exchanged through the PP from the outside. Not convenient.

- In the optimal configuration, the part **above the pinch point** acts as a **heat sink** to absorb the **minimum amount of heat** Q_{hot} from outside.
- Similarly, the part **below the pinch point** acts as a **heat source** releasing the minimum amount of heat Q_{cold} to the ambient.

Graphical method: composite curves



To achieve **maximum energy recovery:**

- Don’t exchange heat across the pinch point
- Don’t use external heat sources below the pinch point
- Don’t reject heat to the environment above the pinch point

Selection of minimum temperature difference

- As **ΔTmin increases**, there is an increase in the **heat to be released** to the environment and the **heat required** from the outside, thus **decreasing the amount of heat that can be recovered** in the system.
- As **ΔTmin increases**, however, there is a **decrease in the surface area required** for heat exchange.
- In fact**, low ΔTmin would be thermodynamically convenient**, but are generally **more expensive**.

How do I choose the **ΔTmin that makes the best compromise** between thermodynamic cost and capital cost?

1. Calculation of the **total exchange surface required by the energy system**, evaluating the influence of ΔTmin on costs.
2. Evaluate the influence of ΔTmin on capital cost **only around the pinch point**, without analyzing the entire HEN.

Problem table

- More precise and especially a more practical method than the graphical method.

Input data:

- **Initial and final temperatures** of the heat flows of a system
- **Heat capacity** of the flows
- **ΔTmin**

Purpose → to highlight the maximum amount of heat that can be transferred from a certain temperature level to the levels below, i.e. to ensure that there is no heat transfer across the pinch point

Problem table

Example 1:

Stream	Type	Cp (kW/°C)	Tin (°C)	Tout (°C)
A	Cold	2	20	135
B	Hot	3	170	60
C	Cold	4	80	140
D	Hot	1.5	150	30

ΔTmin = 10°C

We proceed by calculating the SURPLUS or DEFICIT of heat, which represent the horizontal distance in the T-H diagram, to determine whether at each ΔT the heat flux released by the hot flows is greater or less than that absorbed by the cold flows.

Hot flows → -ΔTmin/2

Cold flows → +ΔTmin/2

So that there is contact between CCC and HCC.

Problem table

+ for cold flows
- for hot flows

+ deficit
- surplus

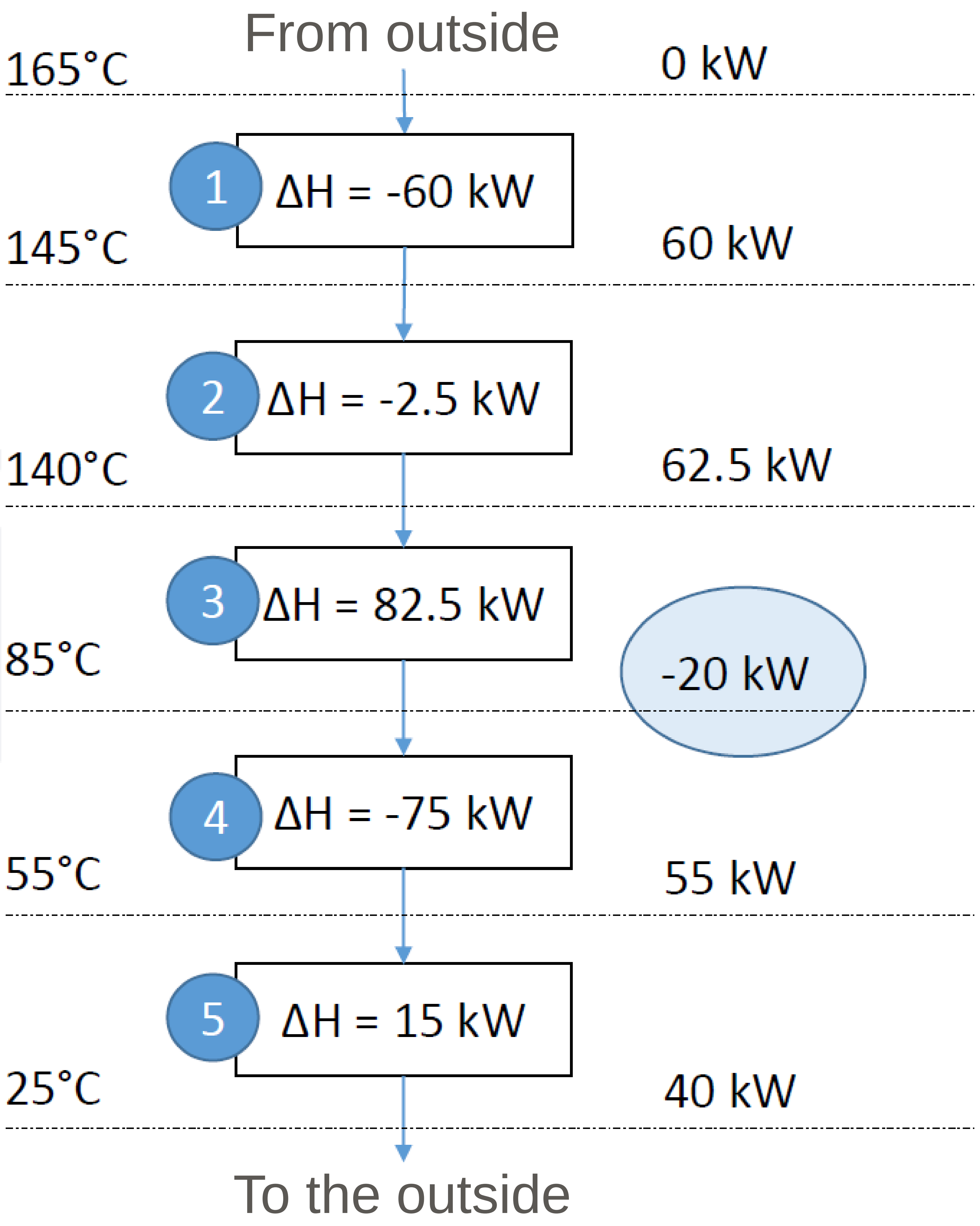
Example 1:

Interval	Tin (°C)	Tout (°C)	ΔT (°C)	Involved flows	Sum Cp (kW/°C)	ΔH (kW)	Surplus / Deficit	Sum Q (kW)
1	165	145	20	B	-3	-60	S	60
2	145	140	5	B, C, D	-0.5	-2.5	S	62.5
3	140	85	55	A, B, C, D	1.5	+82.5	D	-20
4	85	55	30	A, B, D	-2.5	-75	S	55
5	55	25	30	A, D	0.5	+15	D	40

If there is a **heat surplus**, this quantity can be **transferred to the interval below**. If the interval below has a **deficit**, this deficit will have to be **filled by the accumulated surplus**.

Problem table

Example 1:



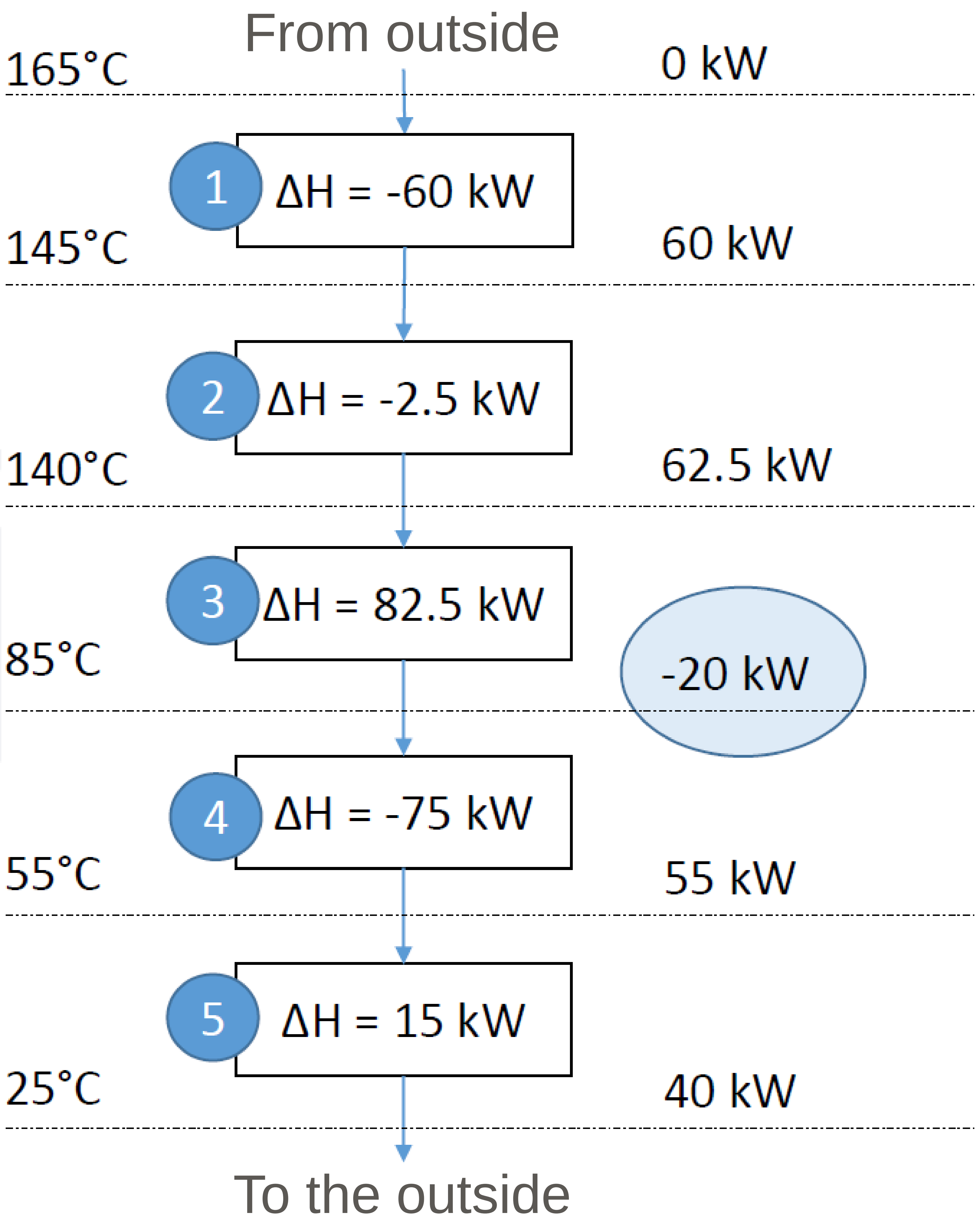
There is a 20 kW deficit that must be met by an external source

+20 kW

The PP is between the 3rd and 4th interval

Problem table

Example 1:



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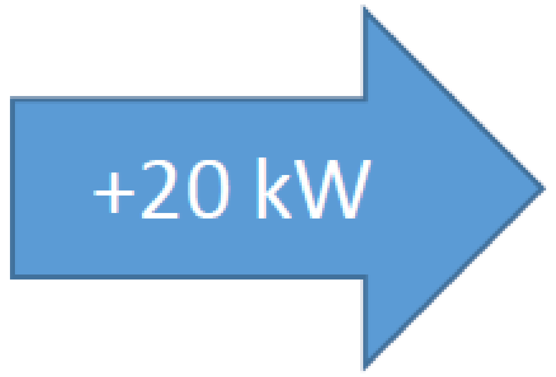

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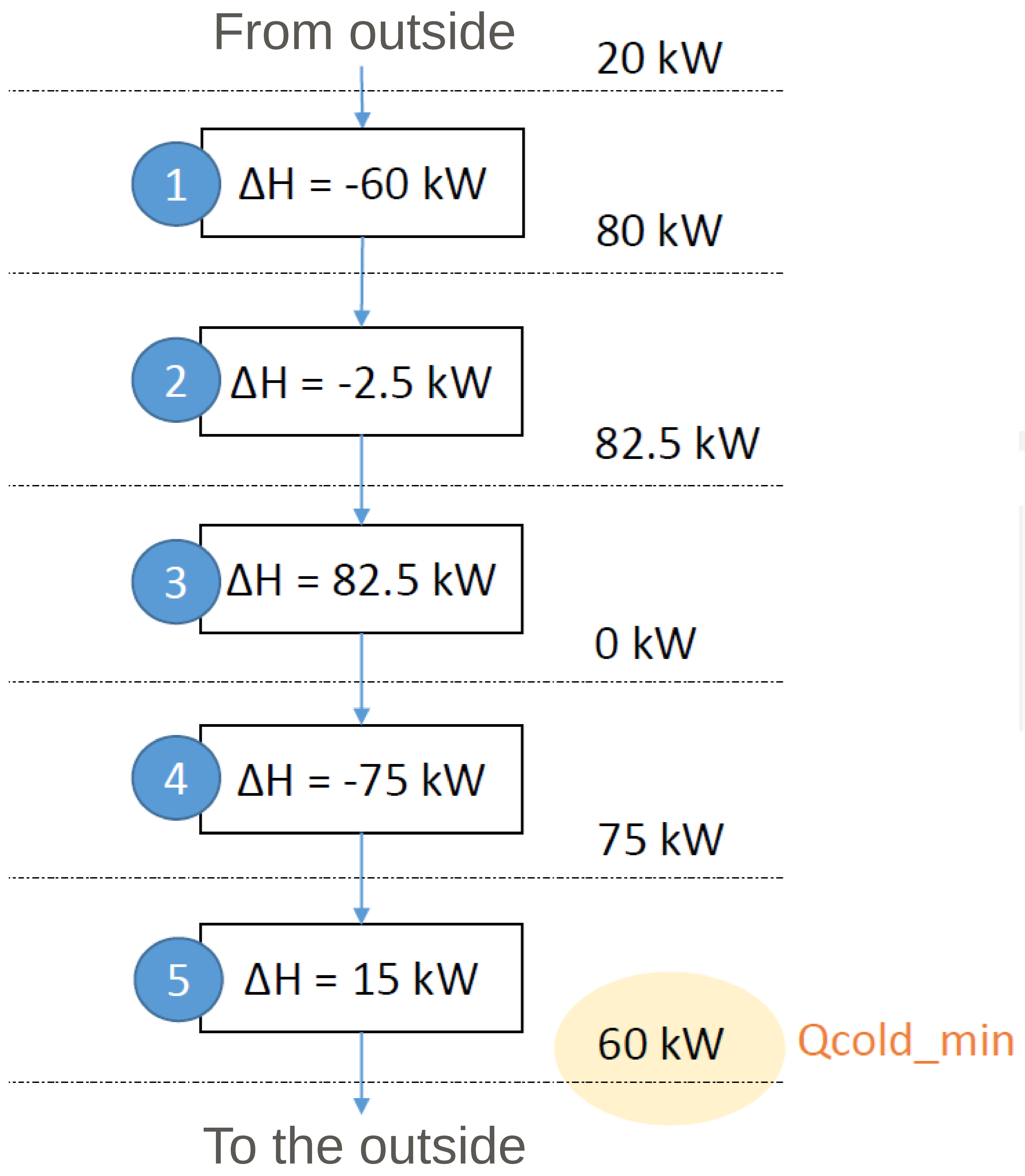


Problem table

Example 2:

Stream	Type	Cp (kW/°C)	Tin (°C)	Tout (°C)
A	Hot	3	140	40
B	Hot	2	80	30
C	Cold	4	60	90
D	Cold	1.5	20	100

$\Delta T_{min} = 10°C$

Hot flows → $-\Delta T_{min}/2$

Cold flows → $+\Delta T_{min}/2$

So that there is contact between CCC and HCC.

Problem table

+ for cold flows
- for hot flows

+ deficit
- surplus

Example 2:

Interval	Tin (°C)	Tout (°C)	ΔT (°C)	Involved flows	Sum Cp (kW/°C)	ΔH (kW)	Surplus / Deficit	Sum Q (kW)
1	135	105	30	A	-3	-90	S	90
2	105	95	10	A, D	-1.5	-15	S	105
3	95	75	20	A, C, D	2.5	+50	D	55
4	75	65	10	A, B, C, D	0.5	+5	D	50
5	65	35	30	A, B, D	-3.5	-105	S	155
6	35	25	10	B, D	-0.5	-5	S	160

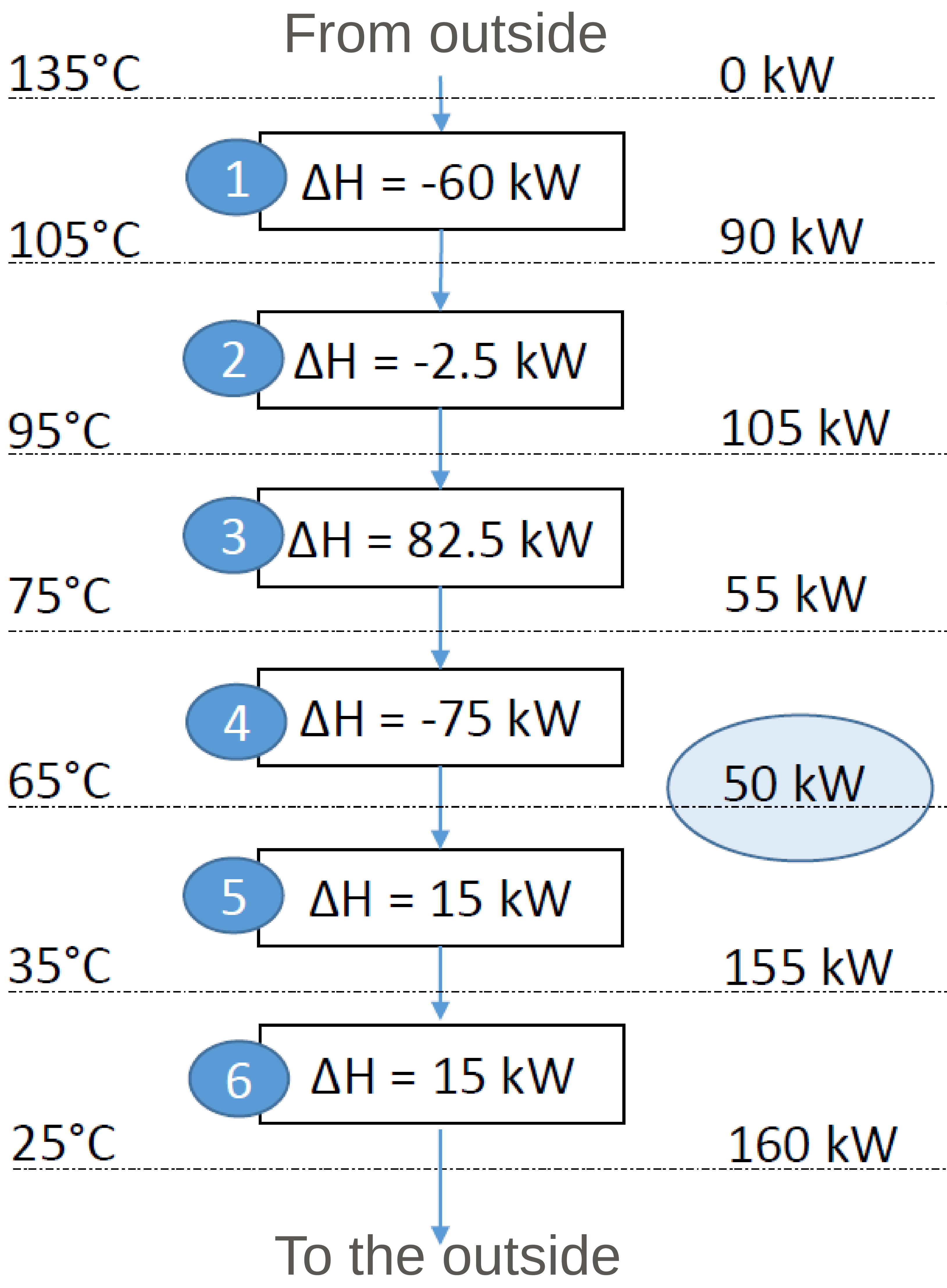
Hot flows → -ΔTmin/2

Cold flows → +ΔTmin/2

So that there is contact between CCC and HCC.

Problem table

Example 2:

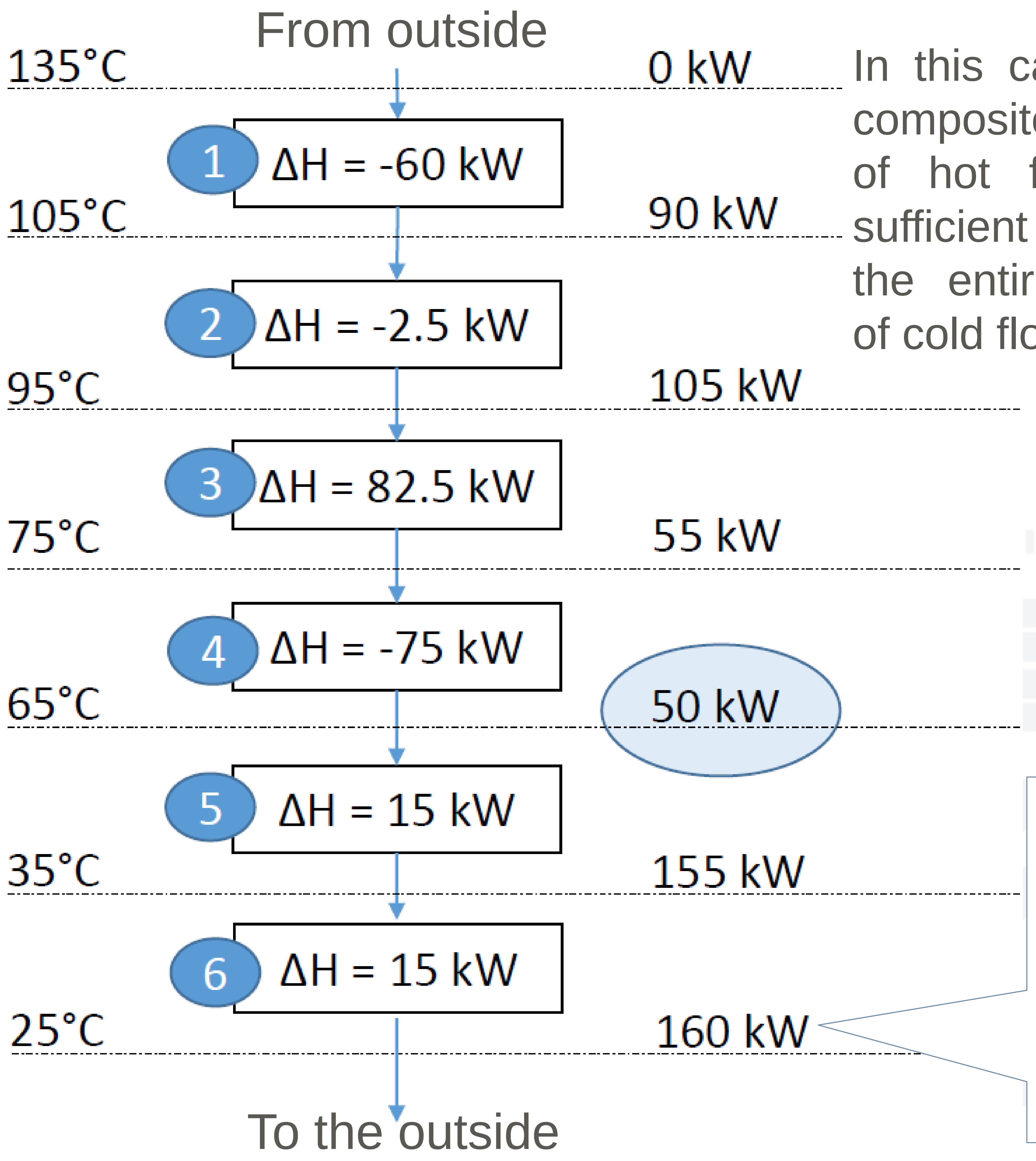


In this case, the composite curve of hot flows is sufficient to cover the entire curve of cold flows.

Take the minimum accumulated heat flux value and set it to zero, subtract 50 kW at all levels.

Problem table

Example 2:



In this case, the composite curve of hot flows is sufficient to cover the entire curve of cold flows.

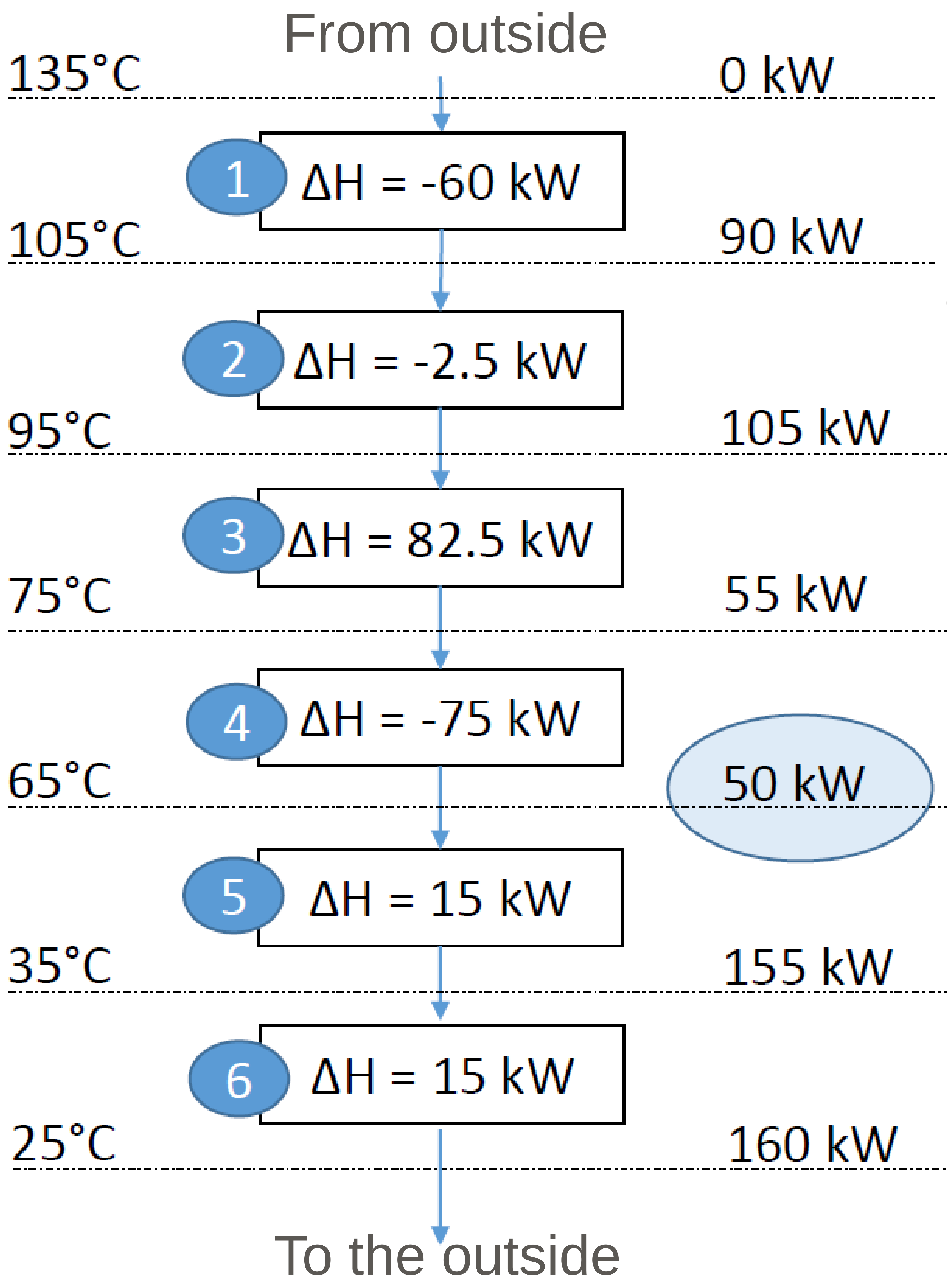
160 kW to be released at low temperature.

Low energy power.

Pinch analysis allows us to see that maximum savings can be achieved by placing the pinch point at 65°C, so the 160 kW are released at a different temperature.

Problem table

Example 2:



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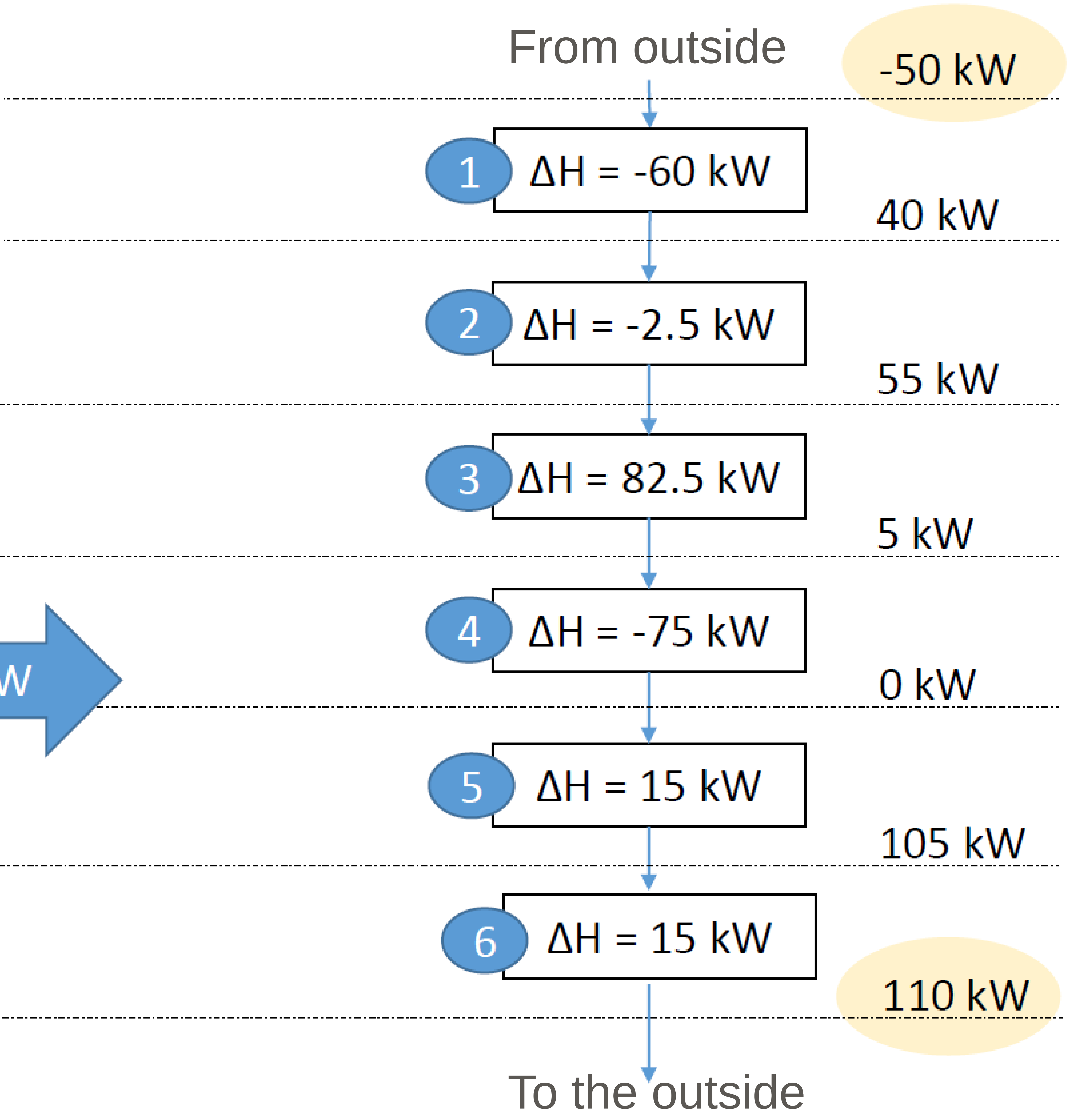

Problem table

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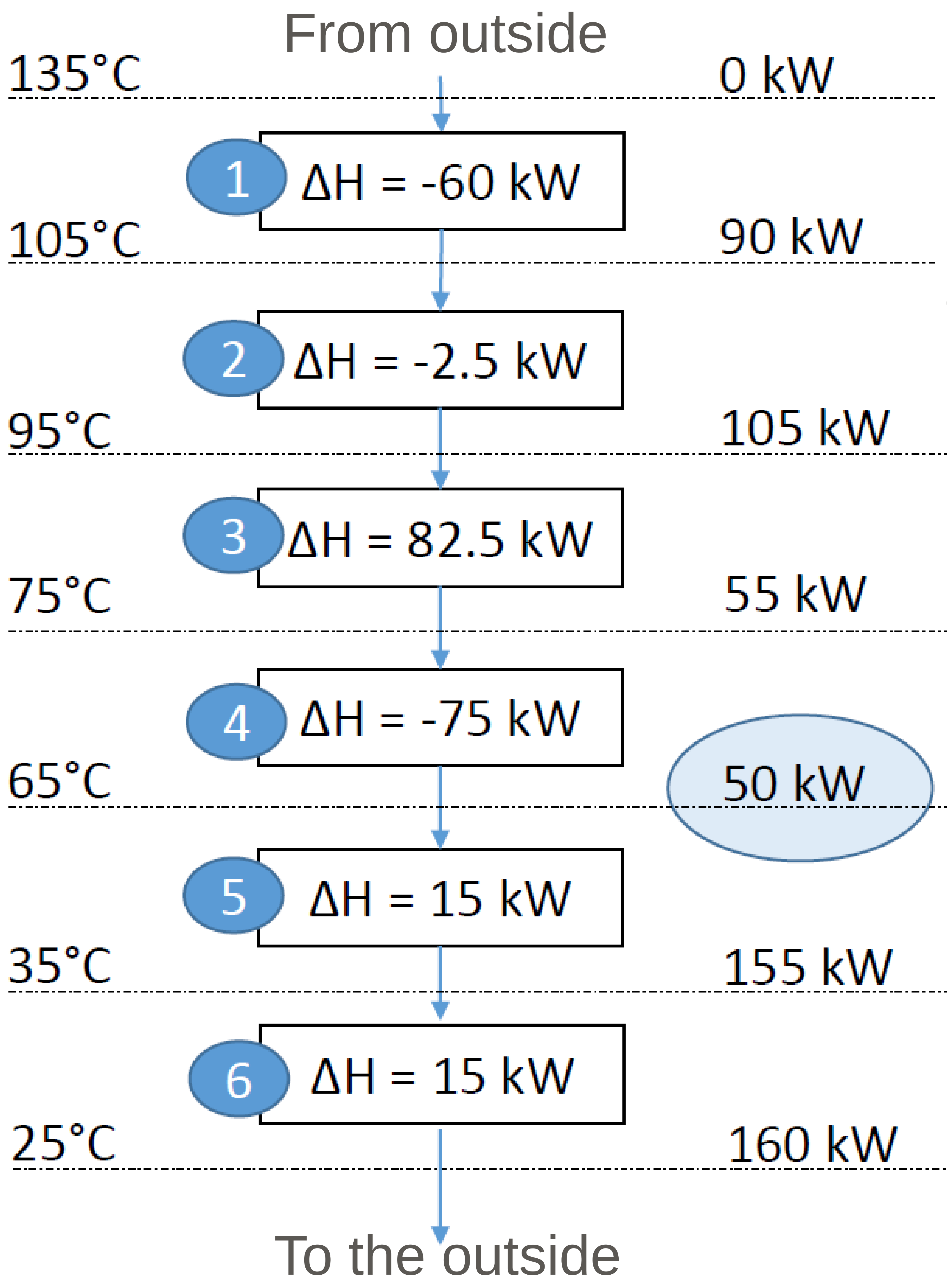
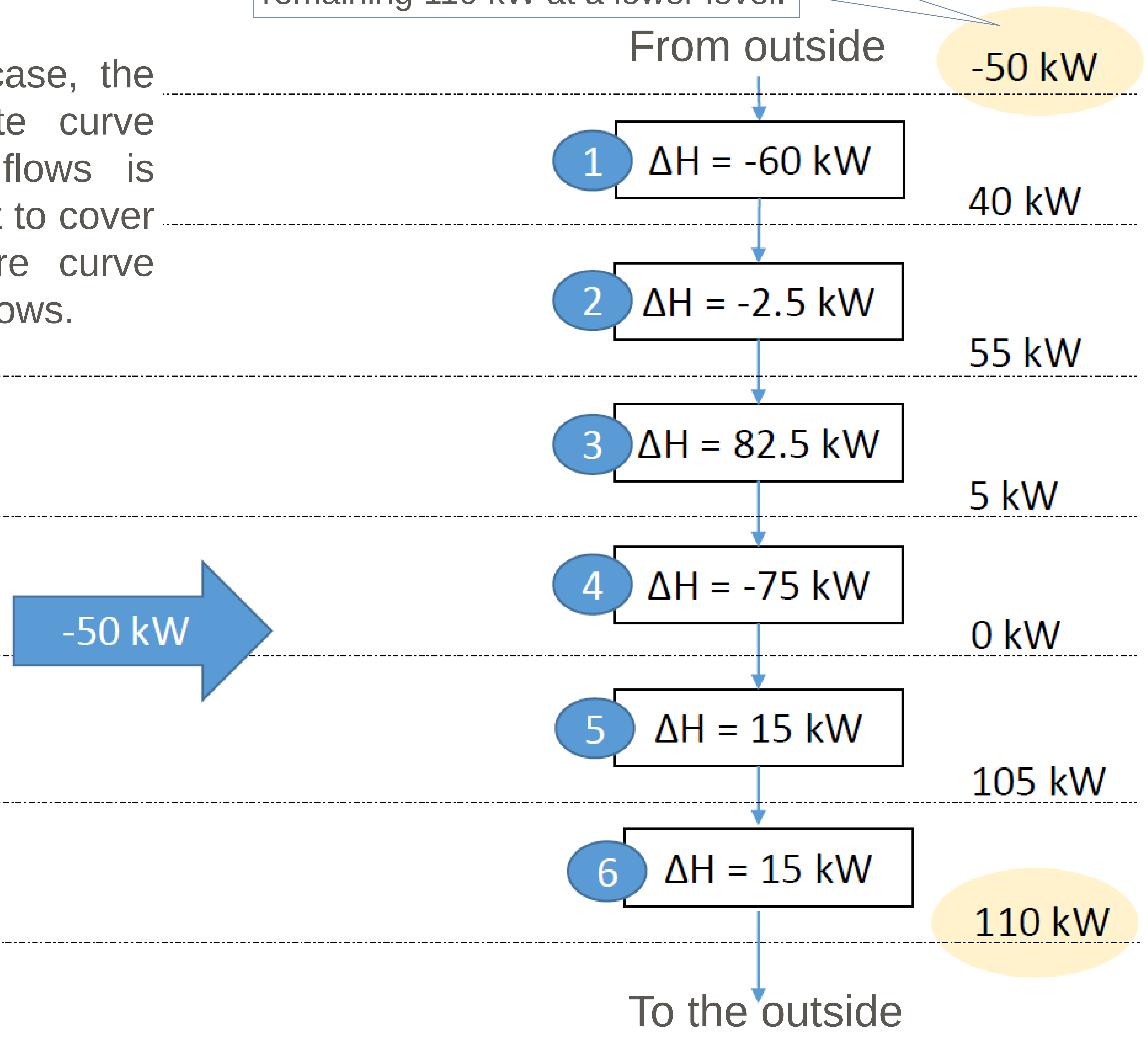


In this case, the composite curve of hot flows is sufficient to cover the entire curve of cold flows.

50kW can be released at a higher temperature level and the remaining 110 kW at a lower level.



Problem table

In this second example, it can be seen that:

- Hot flows are sufficient to heat Cold flows → **no need for external sources**.
- The **entire cold curve is covered** by the warm curve.
- The total excess heat (**160 kW**) would be **released to the ambient**.

- **Pinch Analysis** makes it possible to identify how this excess heat can be **released at different temperature levels**; this could lead to considerable **advantages in terms of heat recovery**.
- It can also be seen that the amount of heat released at a higher temperature level coincides with the minimum value of the cumulative heat flow (50 kW)

Problem table - Overview

From the analysis carried out with the Problem Table, the following cases can be presented:

1. **The minimum value of the cumulative heat flow is <u>negative</u>** → this value represents the **minimum quantity of heat** that must be supplied **by an external source**; adding this value to the beginning of the cascade gives the new values (with 0 kW exchanged at the PP) and the quantity released to the environment will now be the minimum quantity released (Example 1).

2. **The minimum value of the cumulative heat flow is <u>positive</u>** → the system **does not require heat from outside**, because the **internal hot flows are sufficient** to heat the cold flows; the minimum value of the heat flow also corresponds to the minimum amount of heat that can be supplied by the system at high temperature (Example 2).

3. **The minimum value of the cumulative heat flow is <u>zero</u>** → the heat level at which there is <u>zero</u> heat flow, corresponds to the PP; in this case **no heat supply from outside is required**. The heat flow at the end of the cascade represents the amount of heat to be released to the outside.

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