Energy Recovery

HEAT INTEGRATION

- Integrating Heat Pumps and Refrigeration

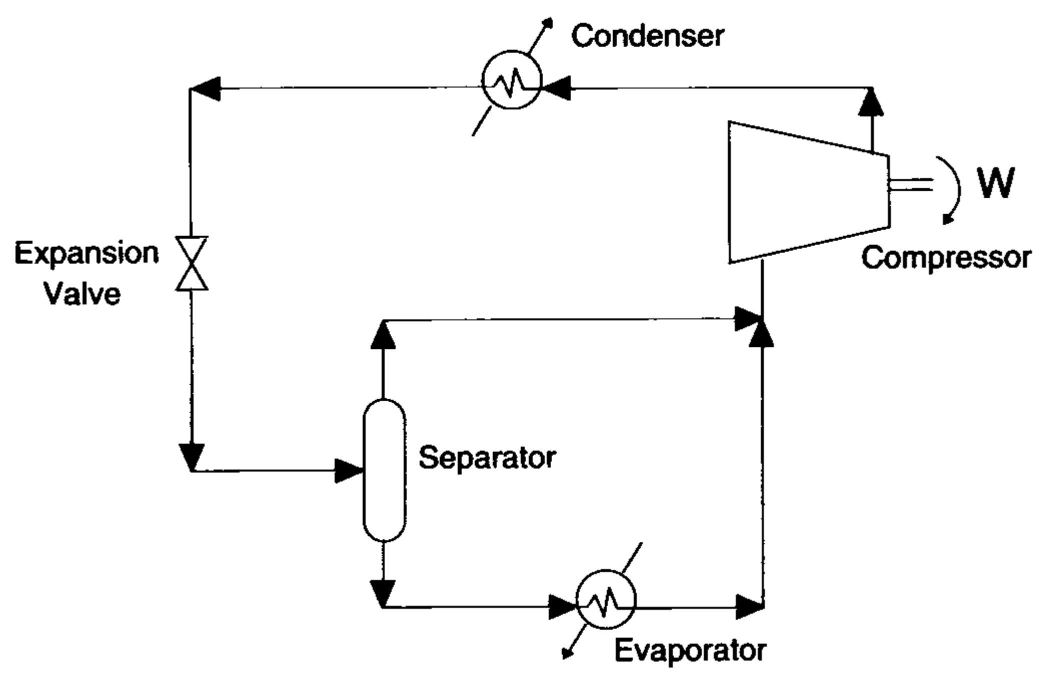
Energy Recovery

Heat Integration *Heat Pumps & Refrigeration*

A schematic of a simple vapour compression heat pump

A heat pump

- absorbs heat at low temperature in evaporator
- consumes shaft work in compressor
- rejects heat at high temperature in condenser.
- expands rapidly and partially vaporises



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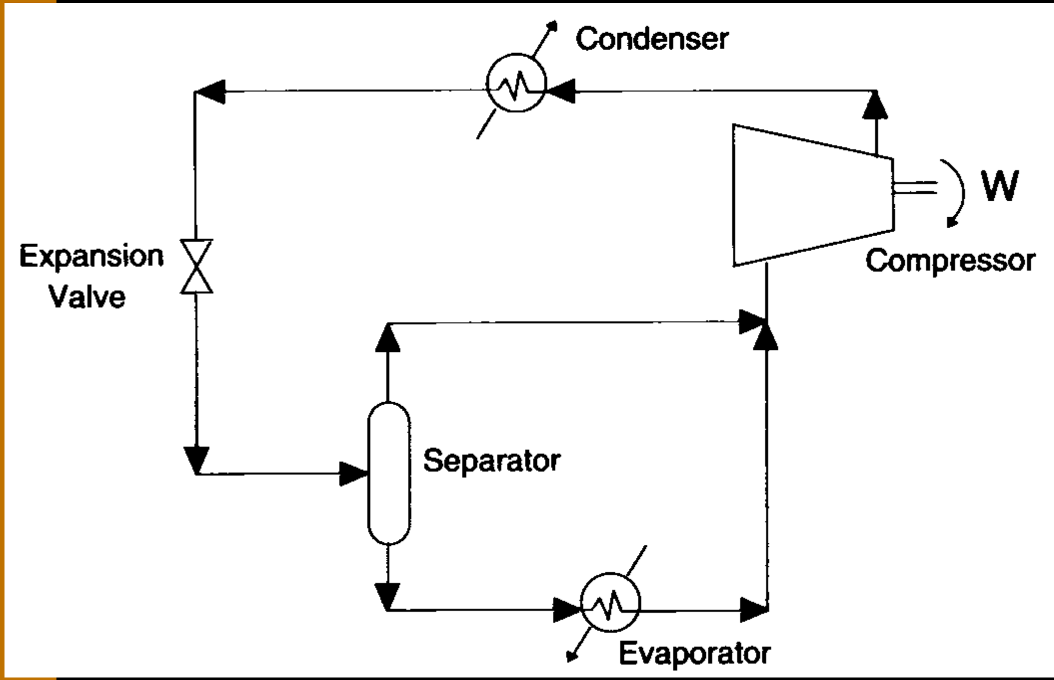
Heat Pumps & Refrigeration

Cycle repeats indefinitely

Working fluid is usually a pure component

ie. has boiling point rather than boiling range

- evaporation and condensation take place isothermally.



Two fundamental ways in which a heat pump can be integrated with the process: across and not across the pinch.

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Heat Integration

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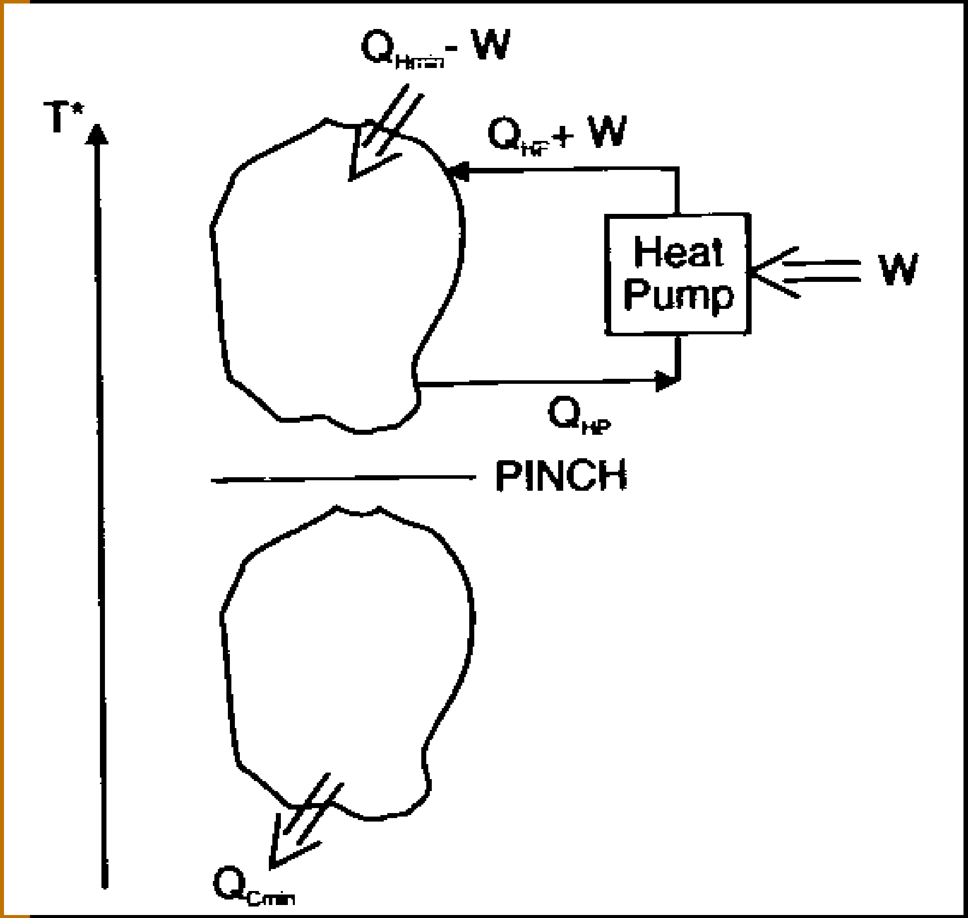
Heat pump placed ***above*** pinch here

- Uses W shaftwork to save W hot utility.

Shaft power is often secondary source of energy, heat is primary source

- If so, converting shaft power back into heat is uneconomical



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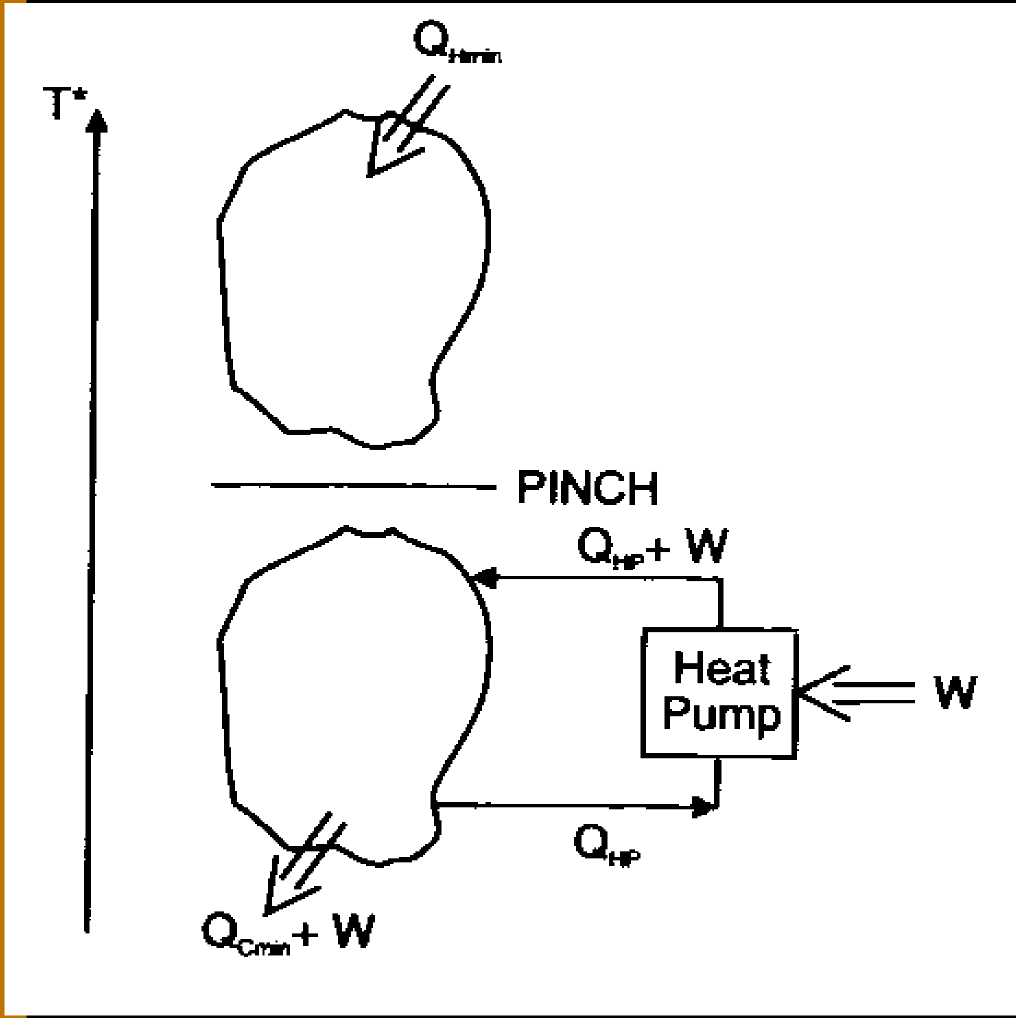
Try placing heat pump below pinch

Shaft power merely made into waste heat

Economically, even worse idea than above pinch



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Heat Integration

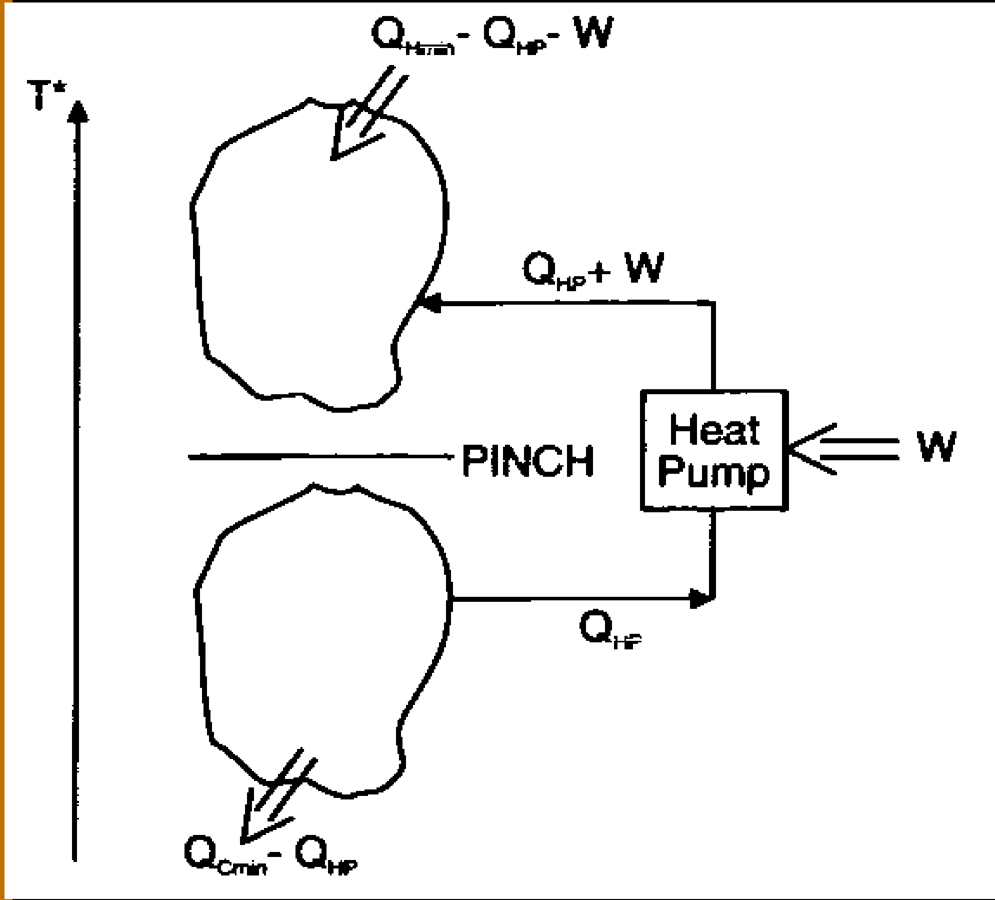
Heat Pumps & Refrigeration

Integration across pinch brings genuine savings

Draws heat away from source and gives heat to sink

Reduces demands on both utilities

Heat pumps should be placed across the pinch



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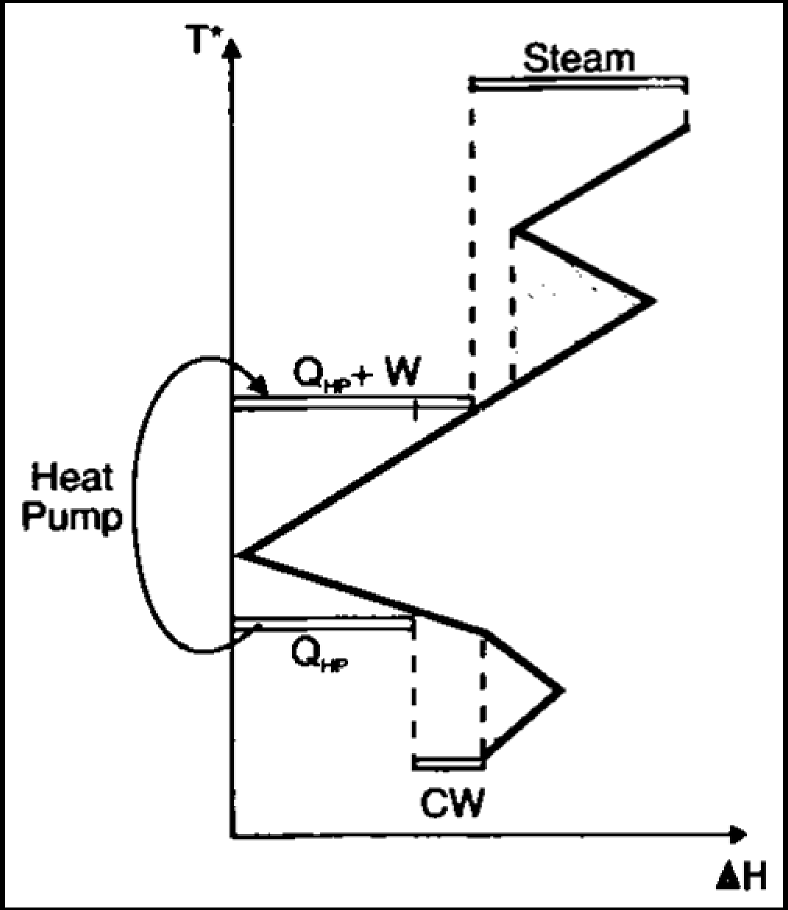
Heat Integration

Heat Pumps & Refrigeration

Principle needs careful interpretation if there are utility pinches.

If so, heat pump replacement above the process pinch or below it can be economic, providing that the heat pump is placed across a utility pinch.

Such considerations beyond the scope of this course.



Using grand composite curve to size well-placed heat pump.

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Heat Integration *Heat Pumps & Refrigeration*

How the heat pump performs determines its coefficient of performance.

The coefficient of performance for a heat pump generally can be defined as the useful energy delivered to the process divided by the shaftwork expended to produce this useful energy.

$$COP_{HP} = \frac{Q_{HP} + W}{W}$$

COP_{HP}: Heat pump coefficient of performance

Q_{HP}: Heat absorbed at low temperature

W: Shaftwork consumed

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High COP_{HP} leads to better economics.

COP_{HP} increases as temperature “lift” with the heat pump decreases

Temperature lifts greater than 25ºC is rarely economical.

Attractive heat pump application normally requires a lift much less than 25ºC.

By having higher load above pinch than below, and not to far apart, COP_{HP} can be complied with

Energy Recovery

A refrigeration system is a heat pump in which heat is absorbed below ambient temperature.

The appropriate placement for refrigeration cycles is that they also should be across the pinch.

As with heat pumps, refrigeration cycles also can be appropriately placed across utility pinches.

It is common for refrigeration cycles to be placed across a utility pinch caused by maximizing cooling water duty.

Such cycles can be much more complex if more than one refrigeration level is involved.

Energy Recovery

Heat Integration *Heat Pumps & Refrigeration*

Use grand composite curve to find

- how much heat from the process needs to be extracted into the refrigeration system
- at what temperature the process can accept rejected heat.

Again, the coefficient of performance determines how the refrigeration system performs.

For refrigeration systems, the coefficient of performance

$$COP_{REF} = \frac{Q_{HP}}{W}$$

The higher the COP_{REF}, the better are the economics.

Energy Recovery

Heat Integration *Heat Pumps & Refrigeration*

The cost of shaftwork required to run a refrigeration system can be estimated approximately as a multiple of the shaftwork required for an ideal (Carnot) system.

The performance of an ideal system is given by:

W_{IDEAL}: Ideal shaftwork required for the refrigeration cycle

$$\frac{W_{IDEAL}}{Q_C} = \frac{T_H - T_C}{T_H}$$

Q_C: The cooling duty

T_H: Temperature at which heat enters cycle (K)

T_C: Temperature at which heat leaves cycle (K)

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Heat Pumps & Refrigeration

The ratio of ideal to actual shaftwork is usually around 0.6

$$W = \frac{Q_C}{0.6}\left(\frac{T_H - T_C}{T_H}\right)$$

Where W is the actual shaftwork for the refrigeration cycle.

This is only an approximate method for calculating the performance of refrigeration cycles.

If greater accuracy is required, use thermodynamic properties of the refrigerant being used.

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Heat Integration *Heat Pumps & Refrigeration EXAMPLE*

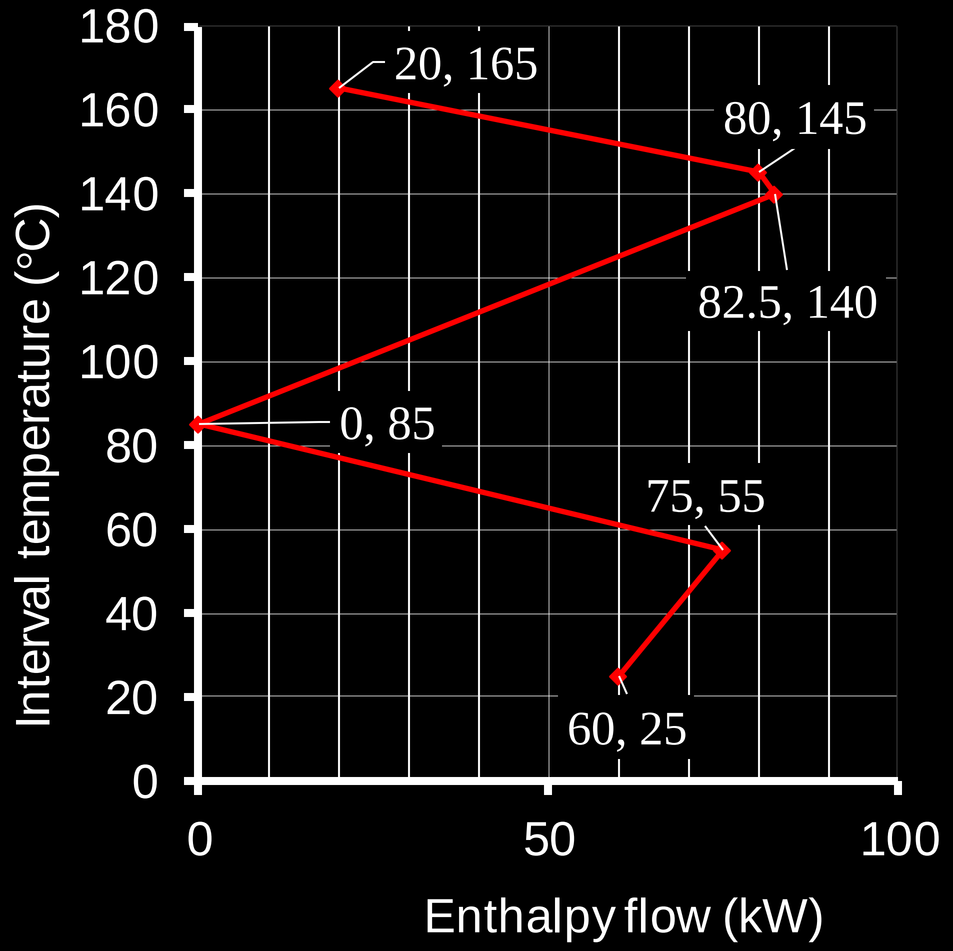
GCC from earlier lecture with 20° lift heat pump proposed

ΔT_{min} here is 10°, so add 5° to cold leg and subtract 5° from hot leg temperatures

This translates as 10° difference in intervals

What is approximate shaftwork needed?

Some trial and error required



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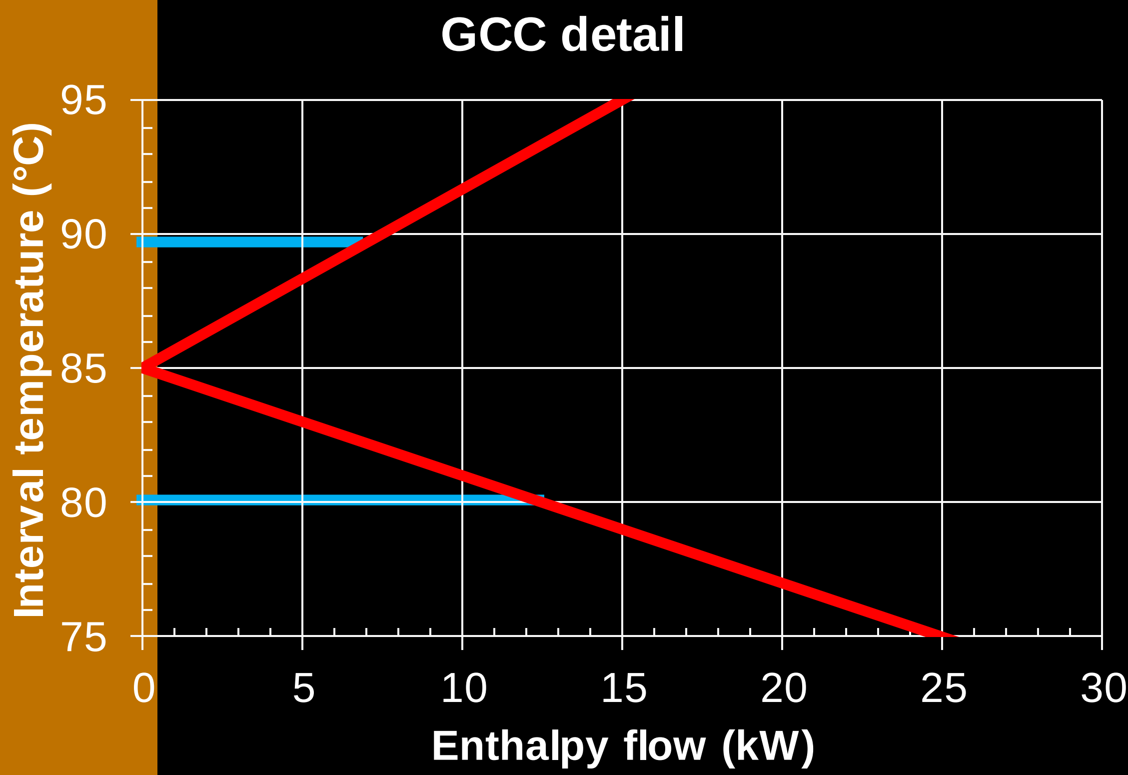
Heat Integration

Heat Pumps & Refrigeration EXAMPLE

First try: absorb all available heat at 75°C and expel at 95°C

Q_C at 80°C (int) = 12.5 kW

Q_H at 90°C (int) can be as high as 7.5 kW



For heat pump, need $Q_C < Q_H$

Need to move up to decrease Q_C but increase Q_H

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Heat Integration

Heat Pumps & Refrigeration EXAMPLE

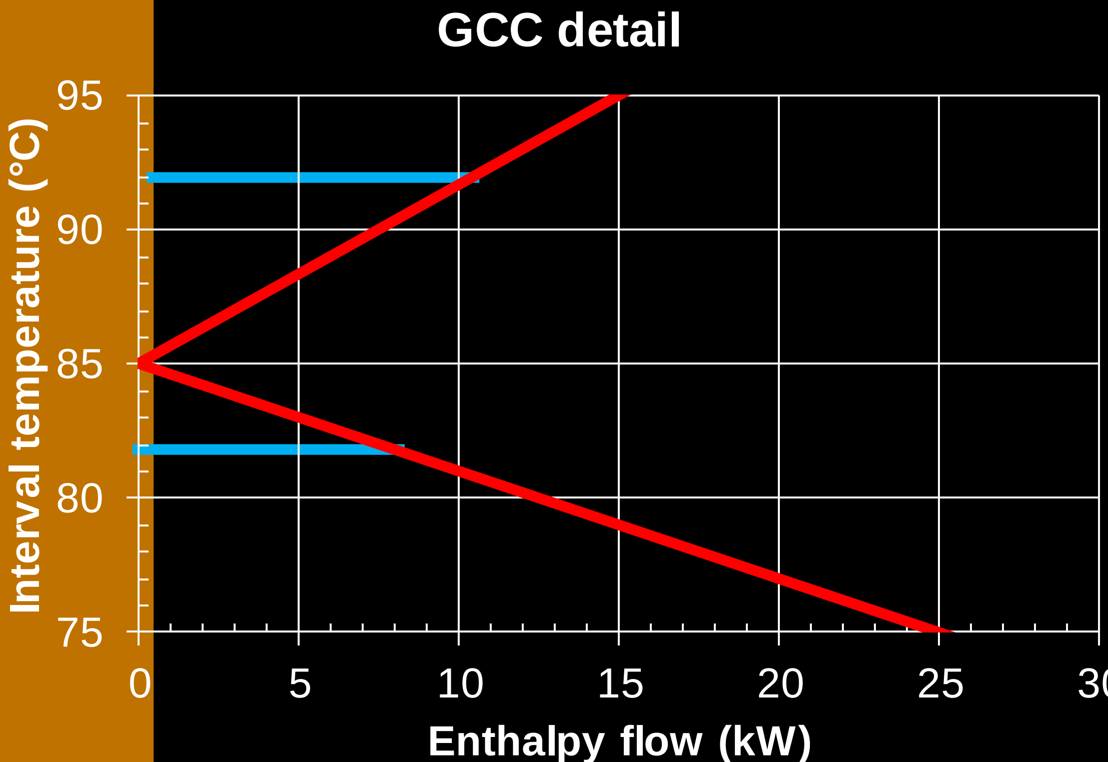
Second try: absorb all available heat at 77°C and expel at 97°C

Q_C at 82°C (int) = 7.5 kW

Q_H at 92°C (int) can be as high as 10.5 kW

$T_C = 273 + 77 = 350$ K

$T_H = 273 + 97 = 370$ K



$$W = \frac{7.5}{0.6}\left(\frac{370-350}{370}\right) = 0.676$$

So 0.676 + 7.5 = 8.176 kW expelled at 92°C (int)

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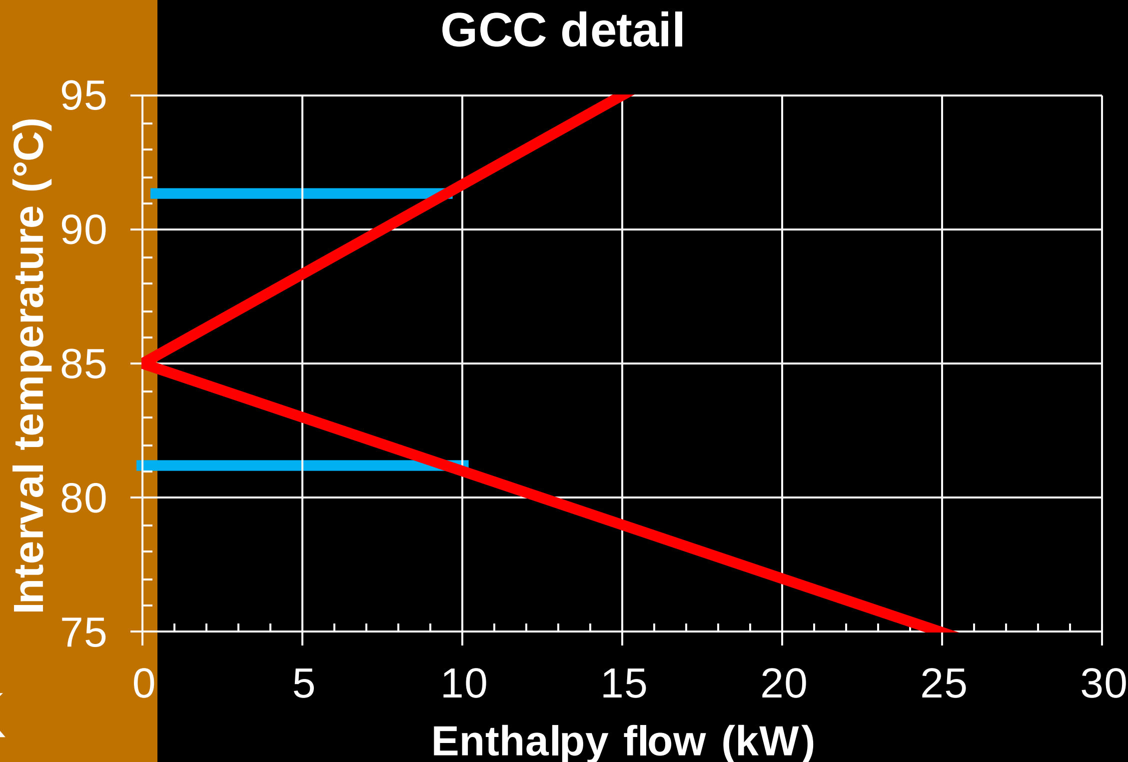
Heat Integration *Heat Pumps & Refrigeration EXAMPLE*

Third try: absorb all available heat at 76°C and expel at 96°C

Q_C at 81°C (int) = 10 kW

Q_H at 91°C (int) can be as high as 9 kW

T_C = 349 K, T_H = 369 K



Here Q_H limits us:

$$\eta_{carnot} = \frac{Q_H - Q_C}{Q_H} = \frac{369 - 349}{369} = 0.0542$$

$9 - Q_C = 0.0542\ (9)$ $Q_C = 8.5122$ kW

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Heat Integration *Heat Pumps & Refrigeration EXAMPLE*

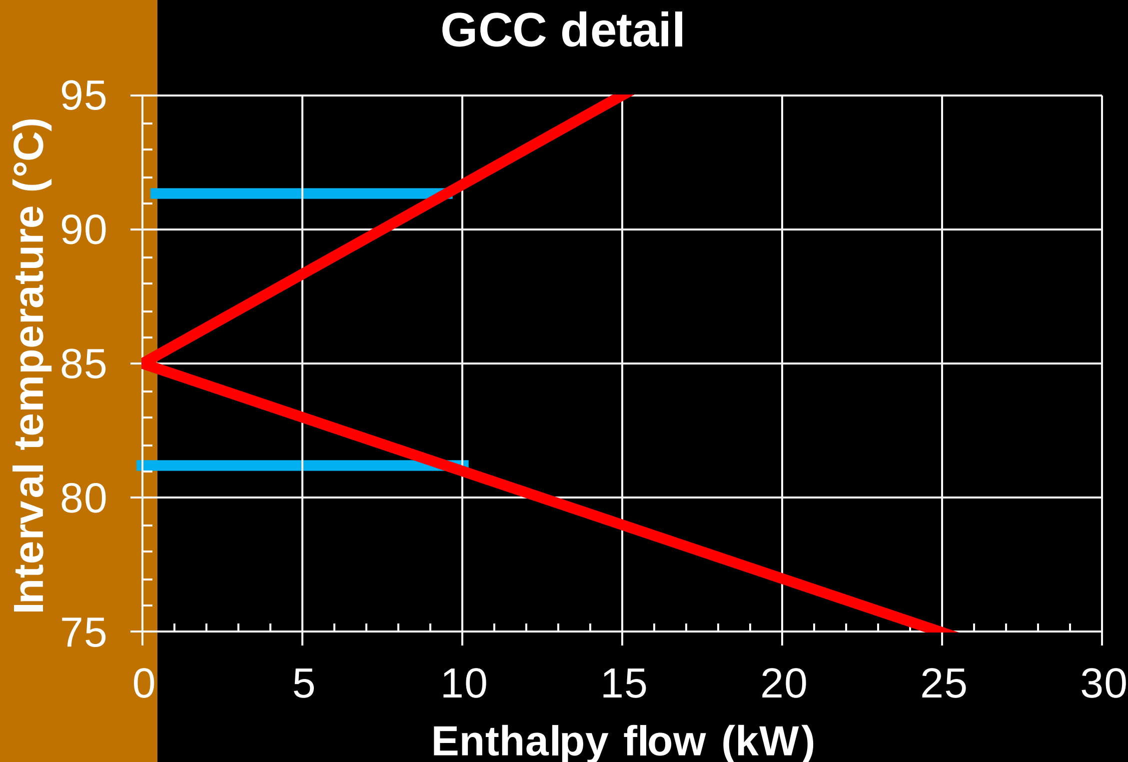
Third try: absorb all available heat at 76°C and expel at 96°C

Highest Q_H of all three so go with it

$W_{IDEAL} = Q_H - Q_C$

$W_{IDEAL} = 9 - 8.5122$

$W_{IDEAL} = 0.4878$ kW



So true work in @60% efficiency is $$W_{actual} = \frac{0.4878}{0.6} = 0.813$$

So shaft work is 0.81 kW

Energy Recovery

Heat Integration

Heat Pumps & Refrigeration EXAMPLE

Shaft work of 0.81 kW

Saves 8.6 kW cold utility (from 60 kW)

Saves 9 kW hot utility (from 20 kW)

Reality is that sometimes extra "utility pinch" is created when full amounts used

This may lead to a more complicated network