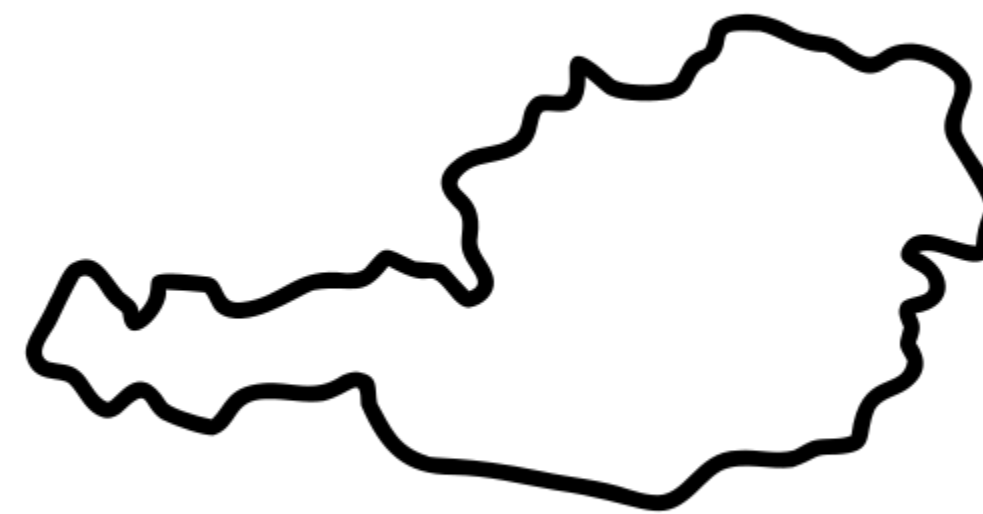


BI-GENERATION IN DATA CENTERS

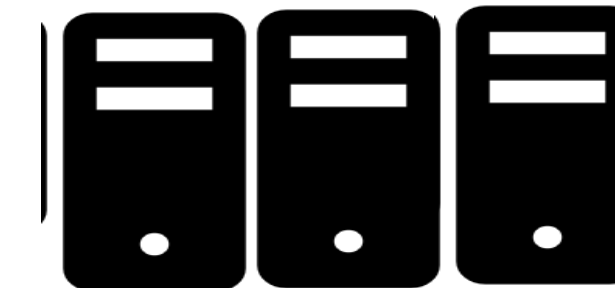
WASTE HEAT RECOVERY FOR DISTRICT HEATING USING HIGH-TEMPERATURE HEAT PUMPS

Gerald Zotter (AEE INTEC), Martin Höller (Wien Energie)

Motivation



DATA CENTER



Electricity consumption (now):

70 TWh/a

< **(6 times)**

415 TWh/a

Source: Statistik Austria (2025)

Source: <https://www.iea.org/reports/energy-and-ai/executive-summary>

Motivation



DATA CENTER



Electricity consumption (now):

1.5 %

415 TWh/a

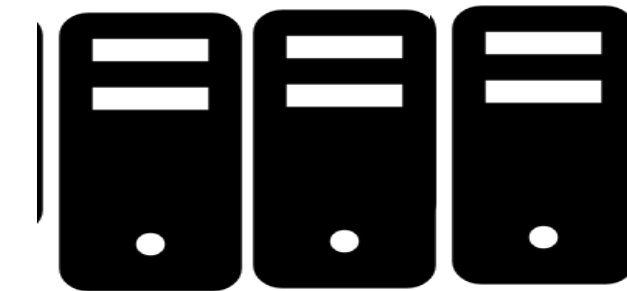
Source: <https://www.iea.org/reports/energy-and-ai/executive-summary>

Motivation

Annual growth rate \approx 15% per year
Data centers are growing much faster than the rest of the energy system



DATA CENTER



Electricity consumption (2030):

3 %

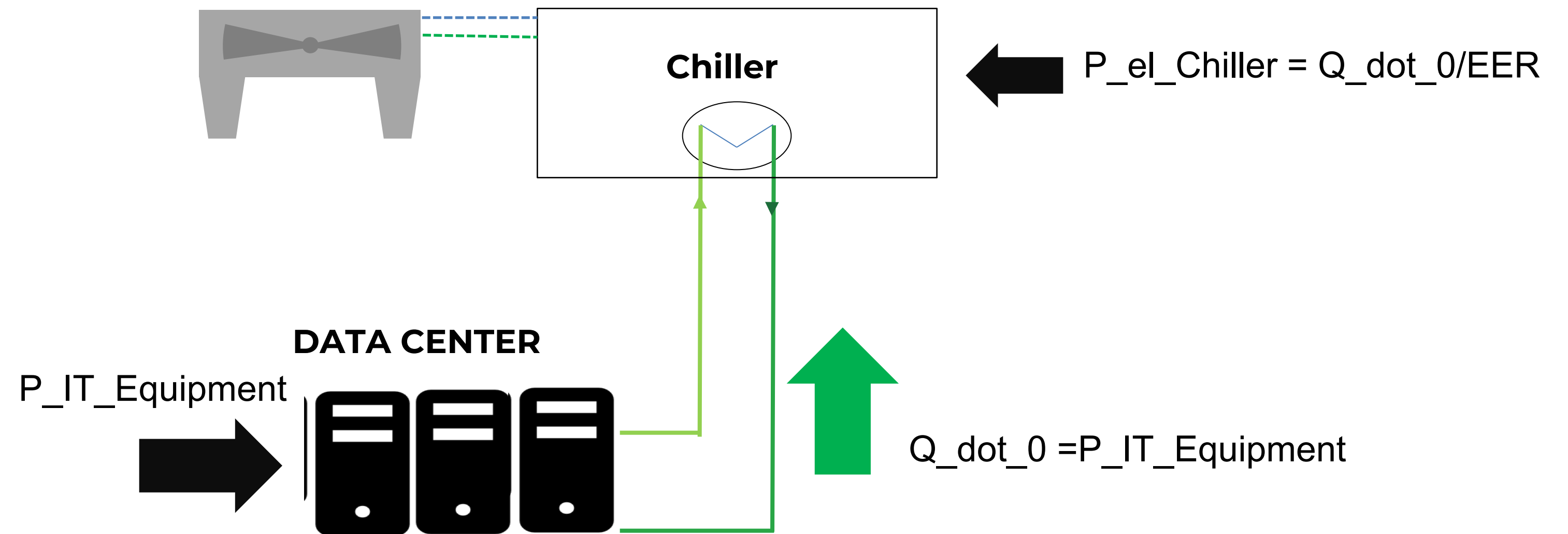
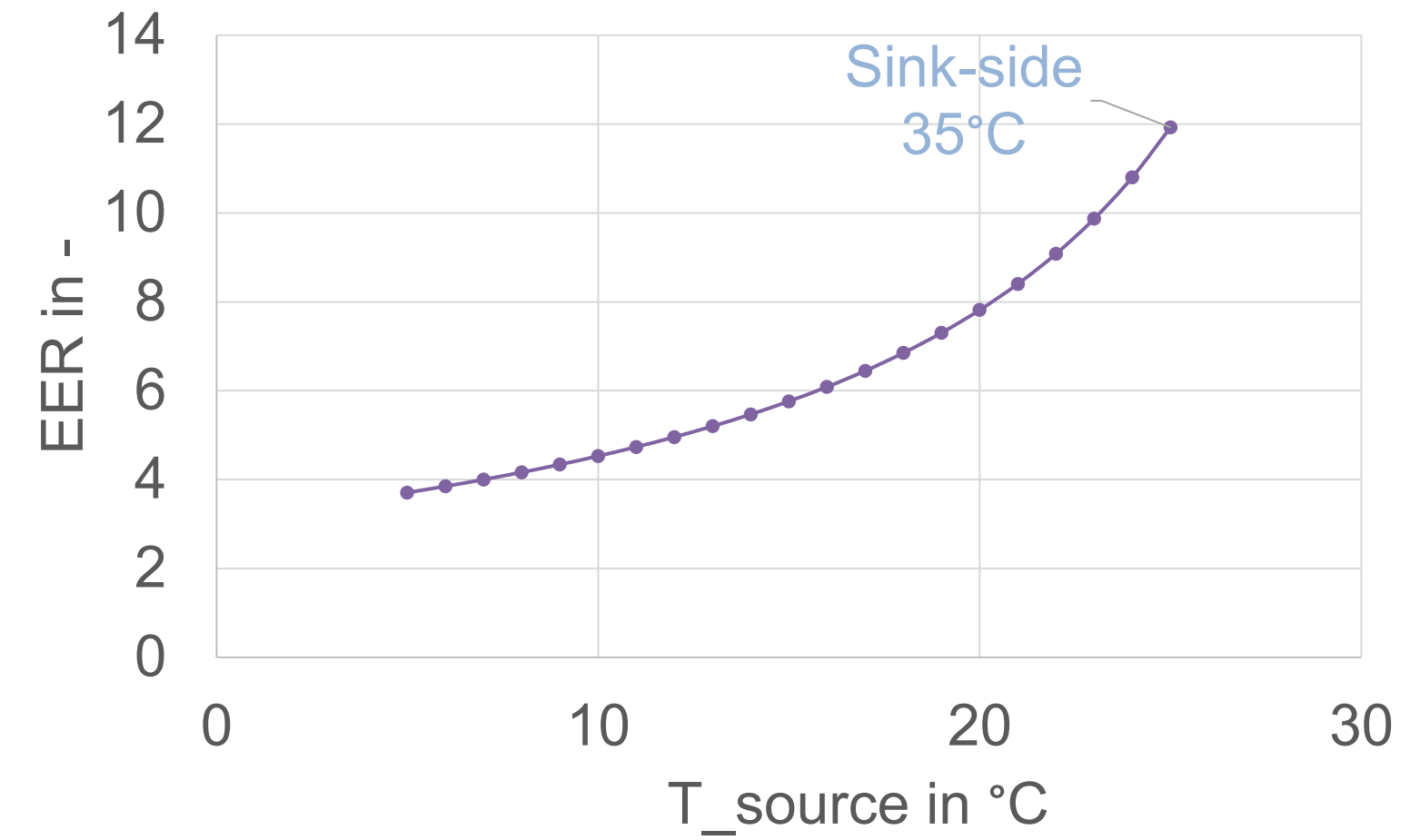
945 TWh/a

Source: <https://www.iea.org/reports/energy-and-ai/executive-summary>

Data Center cooling

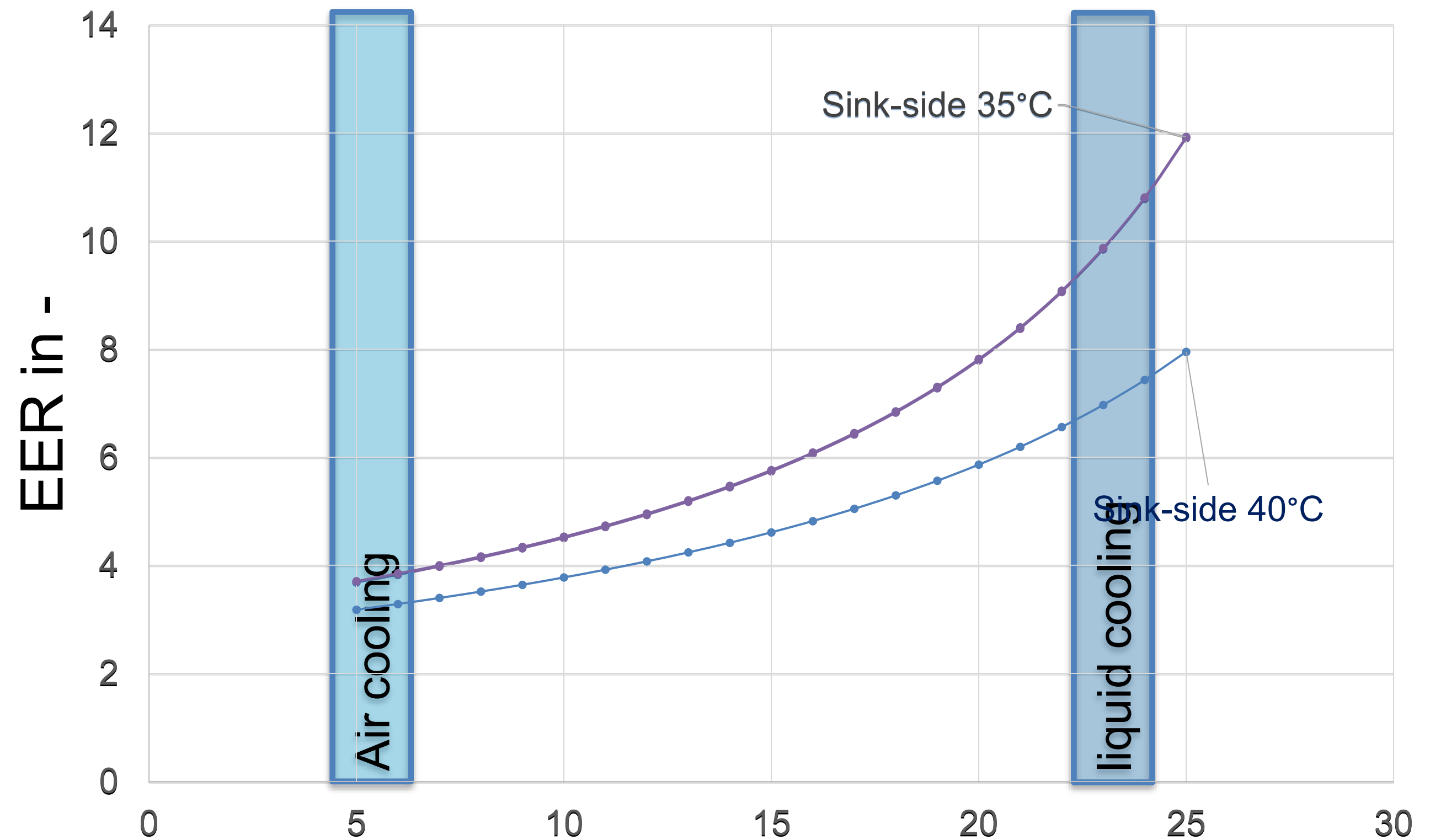
Energy Efficiency

$$EER = \frac{\dot{Q}_0}{P_{el}}$$



Data Center cooling – air vs. liquid

DATA CENTER



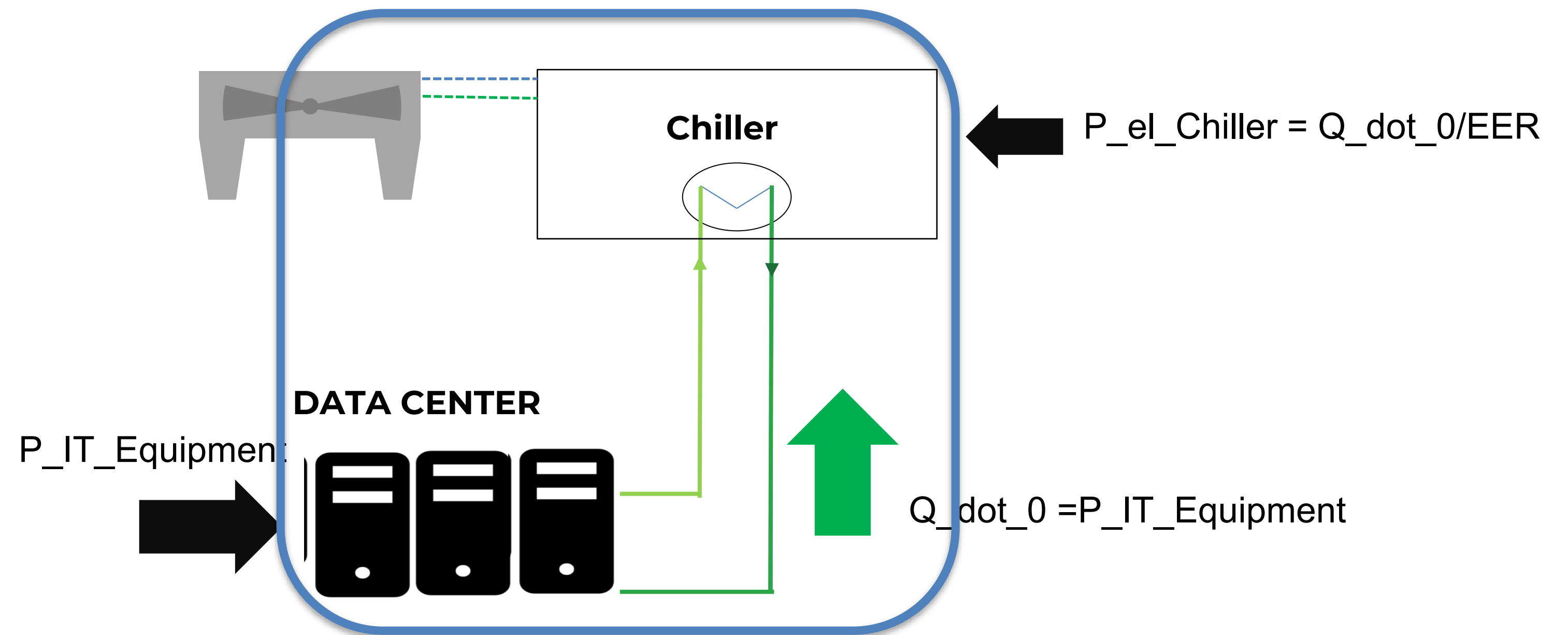
$$\dot{Q} = \alpha * A * (t_{CPU} - t_{Air})$$

$$\dot{Q} = \alpha * A * (t_{CPU} - t_{lig})$$

Data Centers KPIs: Power Usage Effectiveness

$$PUE = \frac{\text{Facility Energy}}{\text{IT Equipment EnergyTotal}} \sim \frac{\text{IT Equipment EnergyTotal} + \text{Chiller Energy}}{\text{IT Equipment EnergyTotal}} \sim$$

$$PUE \sim \frac{\text{IT Equipment EnergyTotal} * (1 + 1/\text{seasonalEER})}{\text{IT Equipment EnergyTotal}}$$



Data Centers KPIs: Power Usage Effectiveness

PUE = 1.0 → perfect (impossible in reality)

Typical values:

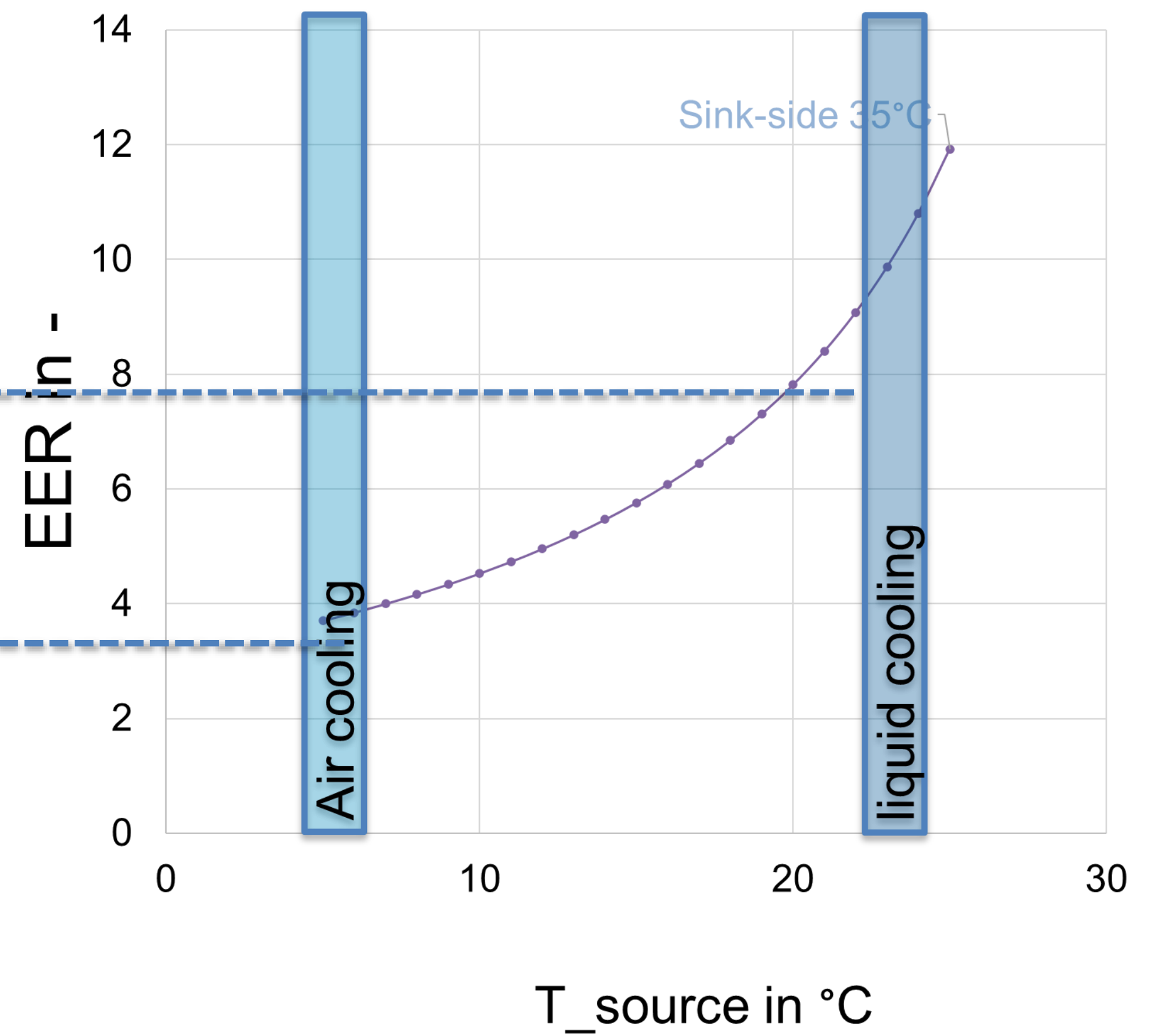
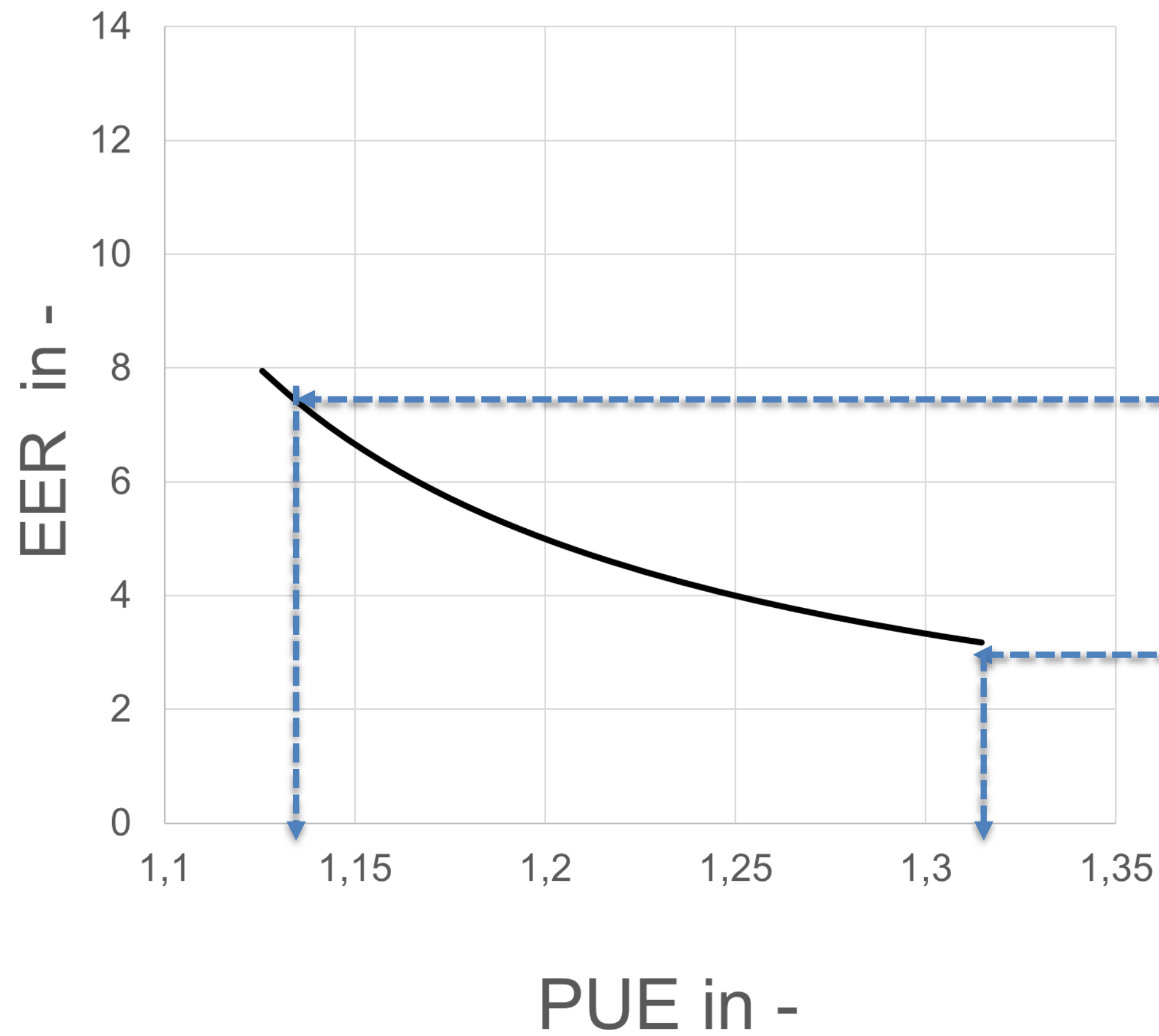
Old data centers: 1.8 – 2.5

Modern hyperscalers: 1.1 – 1.3

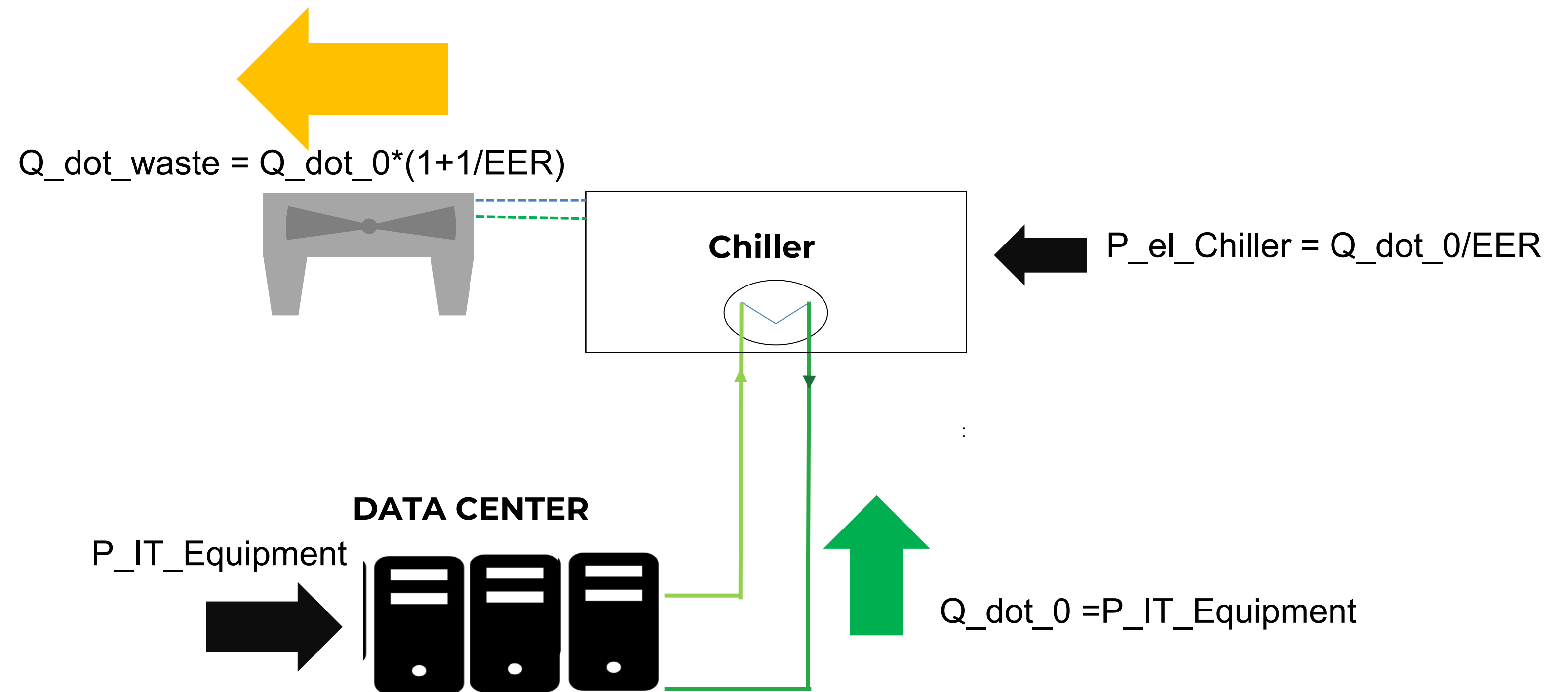
PUE ≤ 1.3

PUE vs EER

DATA CENTER



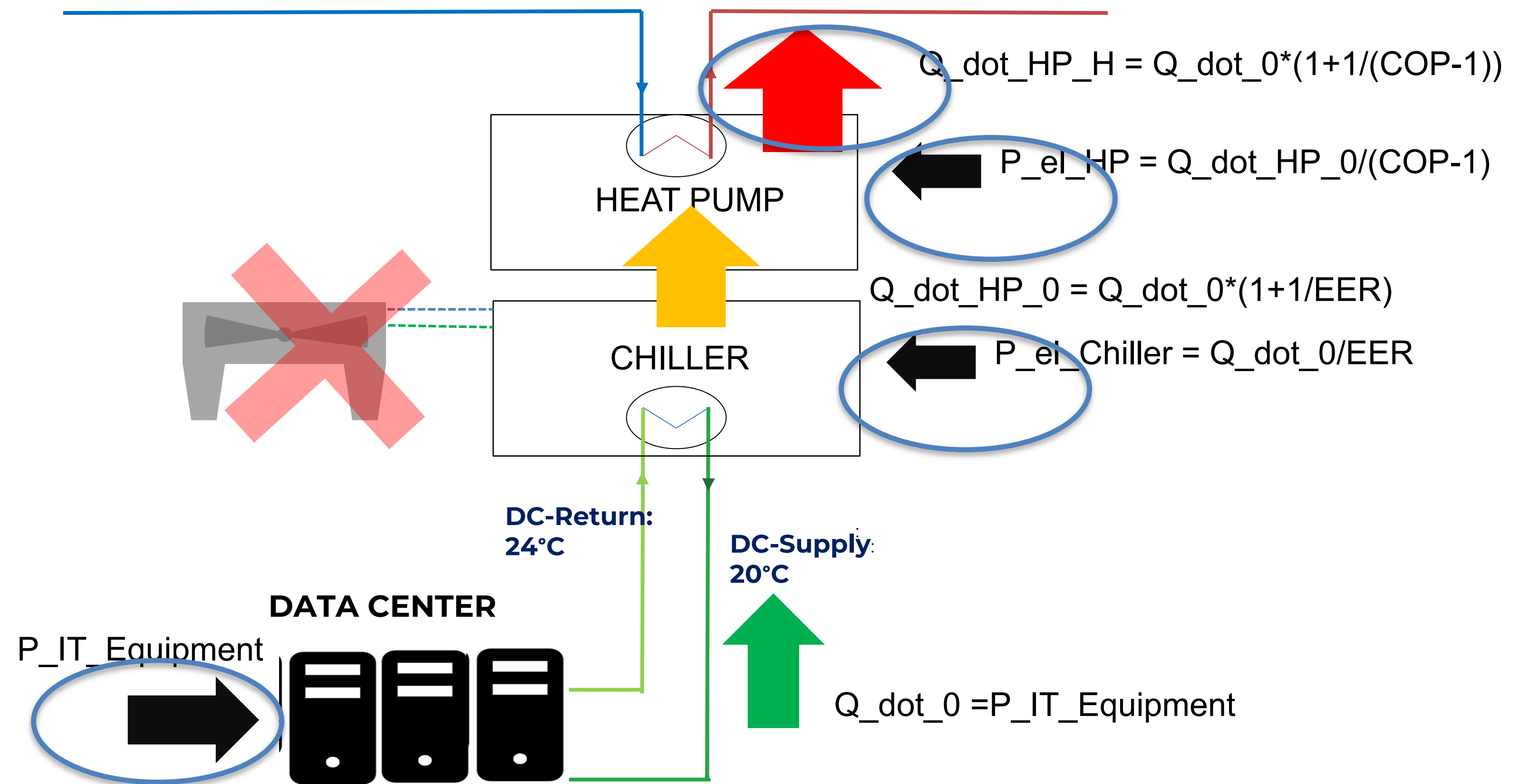
Data Centers: a lot of waste heat @ high temperature level



Data Centers KPIs: Energy Reuse Factor

$$ERF = \frac{Q_{\dot{HP}_H}}{\text{Total Energy Consumed}} = \frac{Q_{\dot{HP}_H}}{P_{IT_Equipment} + P_{el_Chiller} + P_{el_HP}}$$

DH-Return: 60°C
DH-Supply: 90°C



Data Centers KPIs: Energy Reuse Factor

ERF value Meaning

- 0.0 no energy reuse
- 0.2 20% reused
- 0.5 very high reuse

Data Centers KPIs: PUE vs. ERF

ERF should be high

PUE should be low

Miss match because:

- High ERF will influence the PUE in a negativ way

Solution:

$$\text{Energy Reuse Effectiveness (ERE)} = \frac{\text{Total Energy} - \text{Reused Energy}}{\text{IT_Equipment}}$$

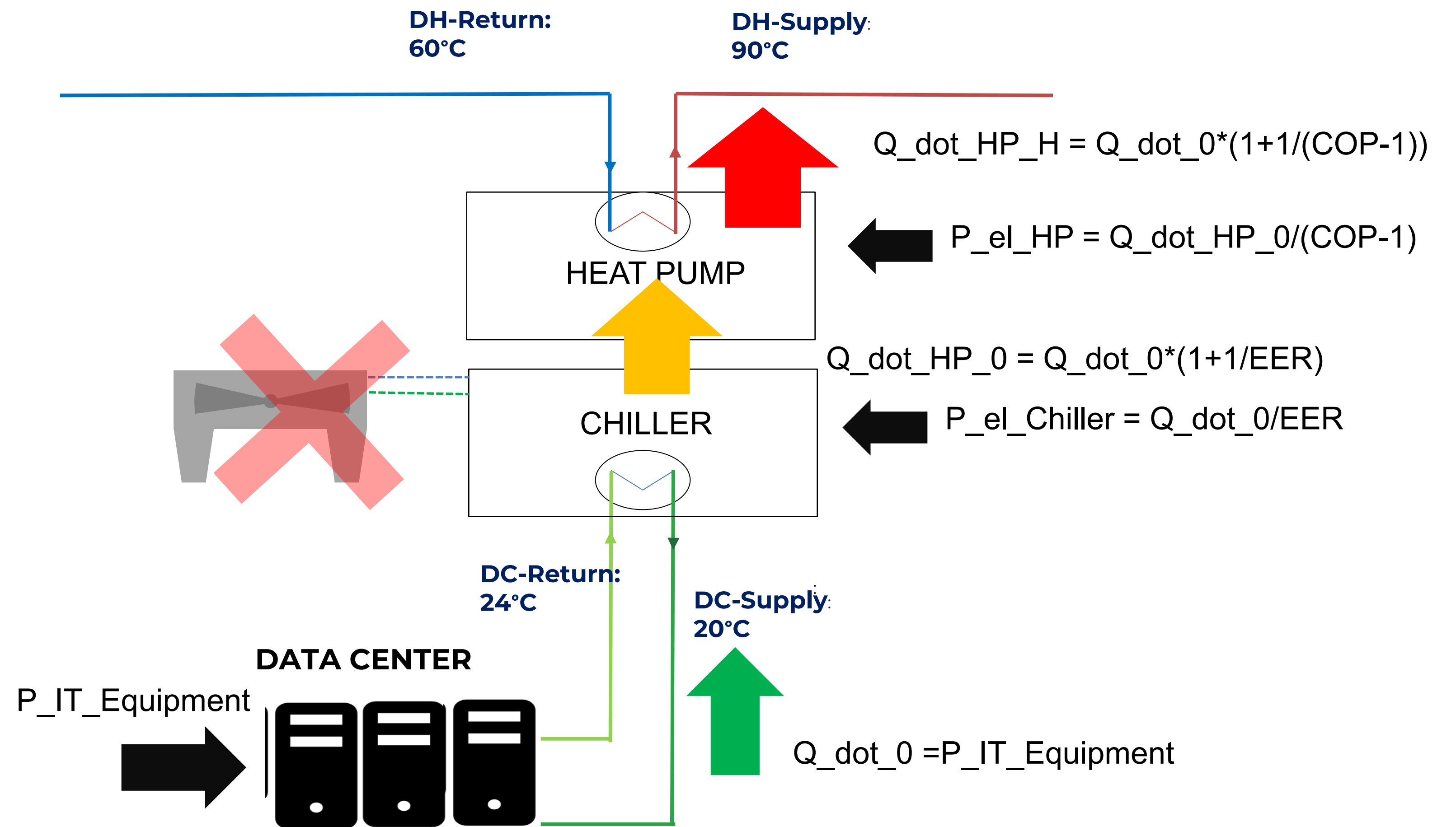
Data Centers KPIs: Energy Reuse Effectiveness

$$\text{PUE} = 1.4$$

$$\text{ERF} = 0.6 \text{ (60\% heat reused)}$$

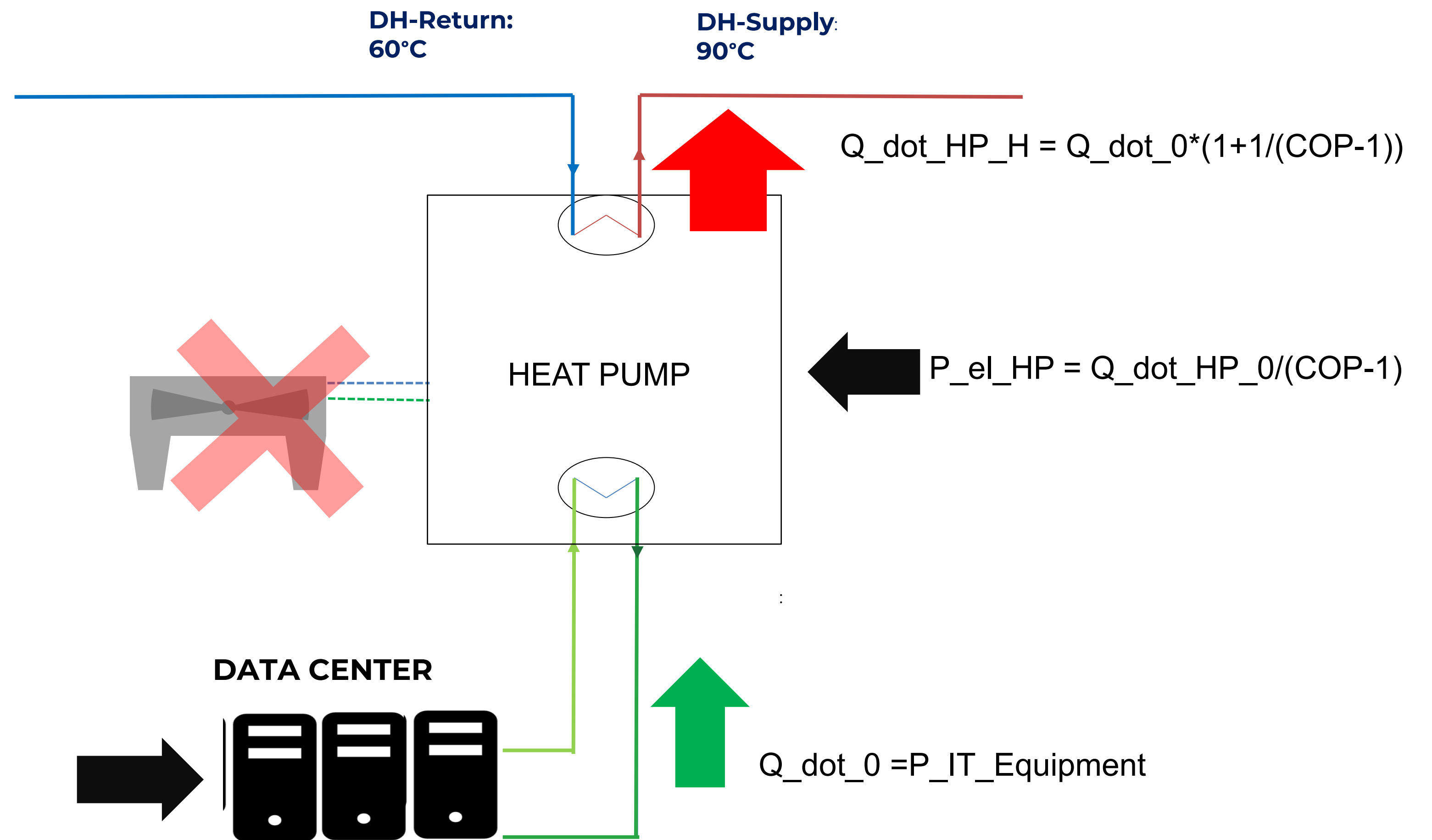
$$\text{ERE} = 1.4 \times (1 - 0.6) = 0.56 \text{ (low is efficient)}$$

Waste heat recovery with heat pump



Coefficient of Performance

$$COP_{COM} = \frac{\dot{Q}_0 + \dot{Q}_H}{P_{el}}$$

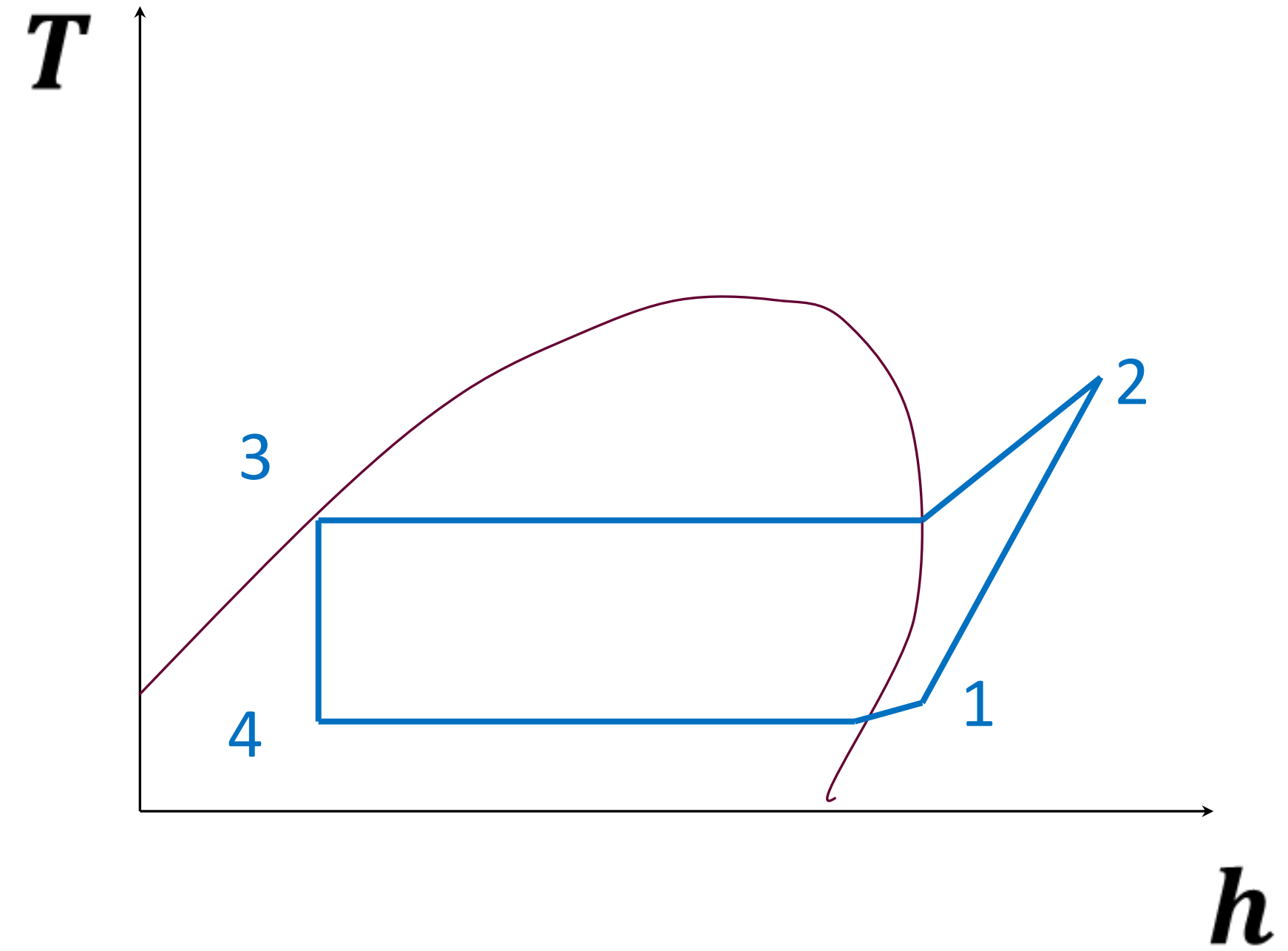
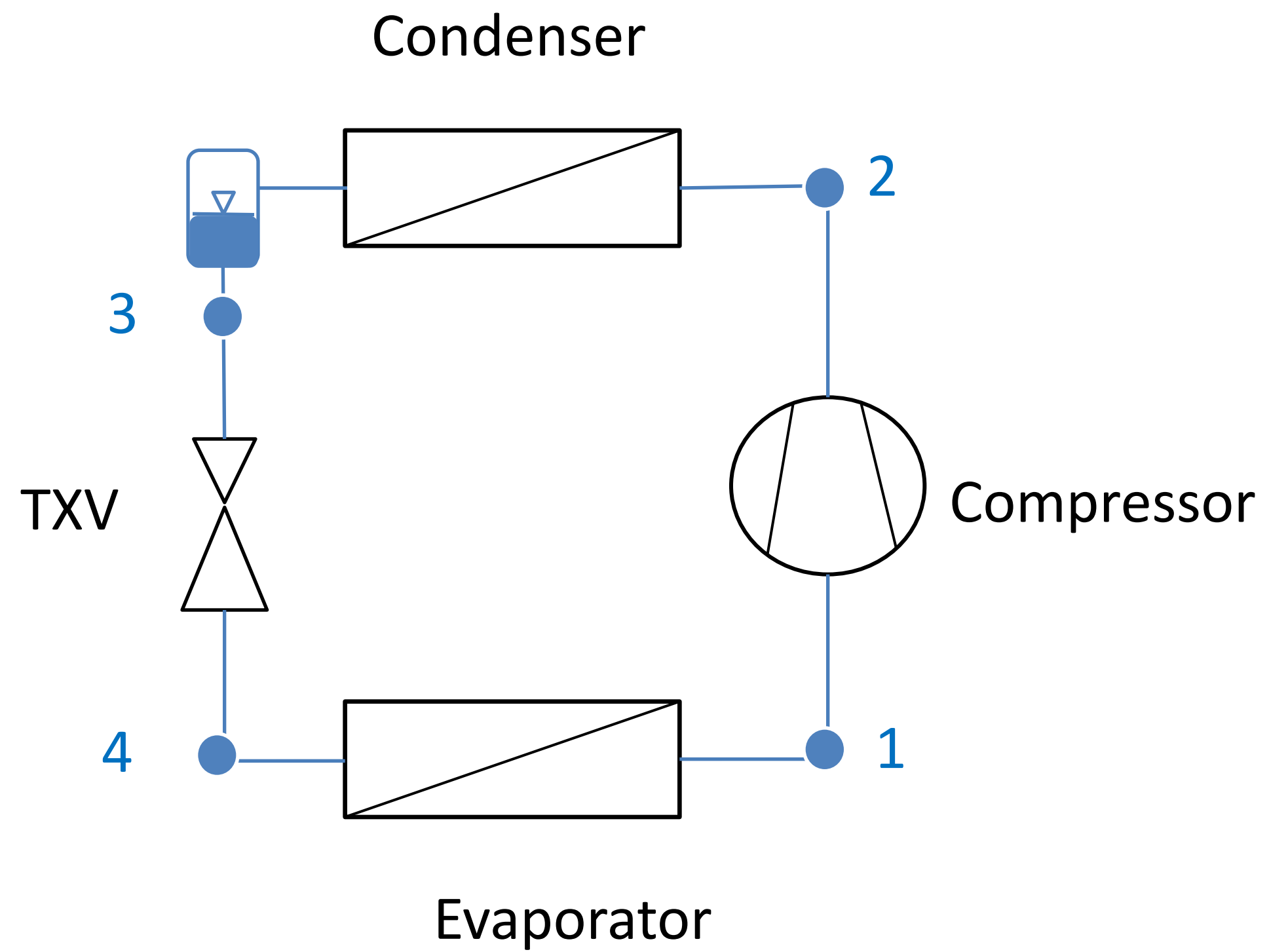


BI-Generation

1 Heat Pump for Cooling and Heating:

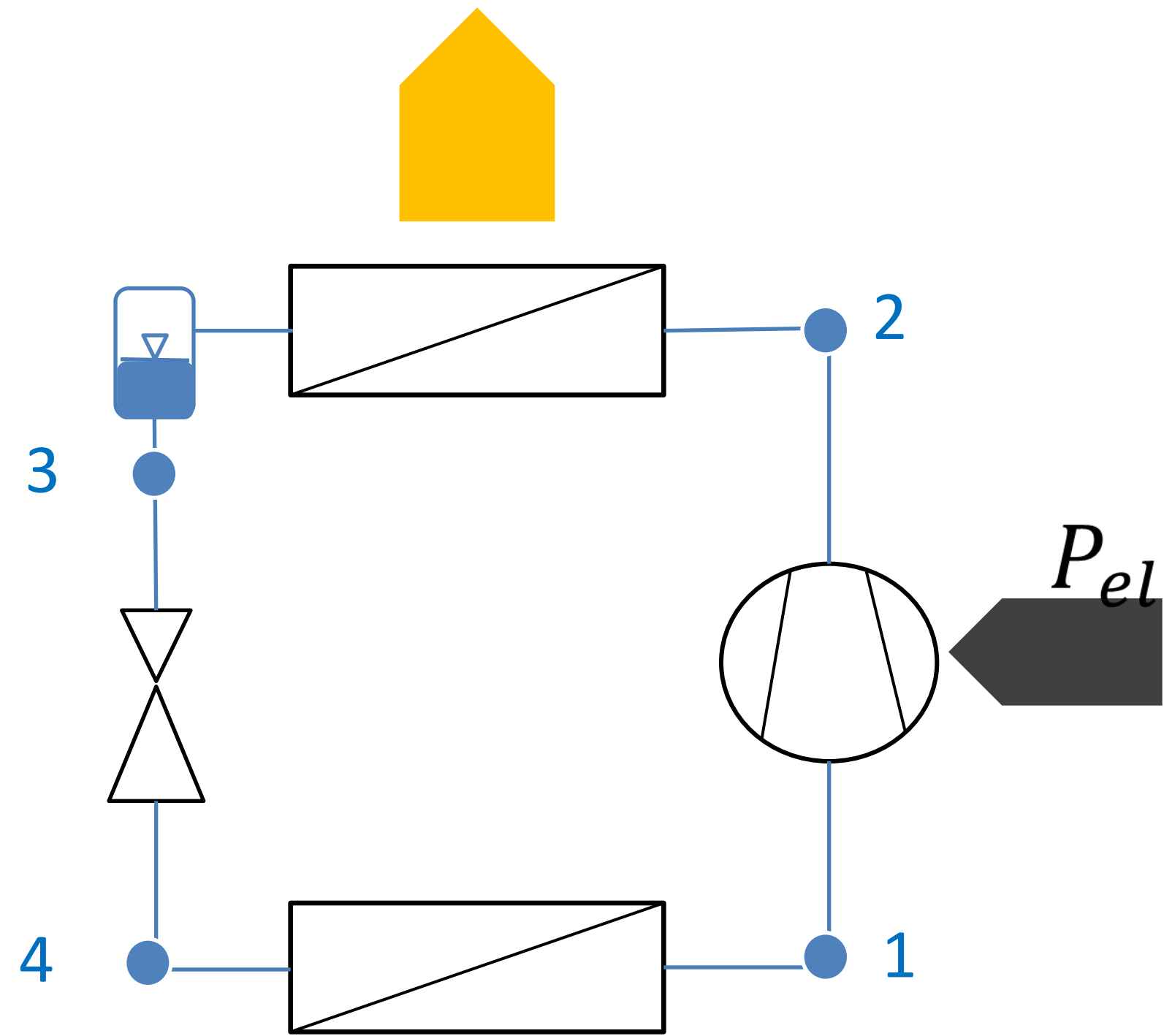
- Half of the CAPEX
- Lowering the Levelized Cost of Heat (LCoH)
- Showing high energy recovery
- Requirements
 - Heat Pump with high Temperature Lift
 - Proper control fulfilling two control targets

Heat Pump

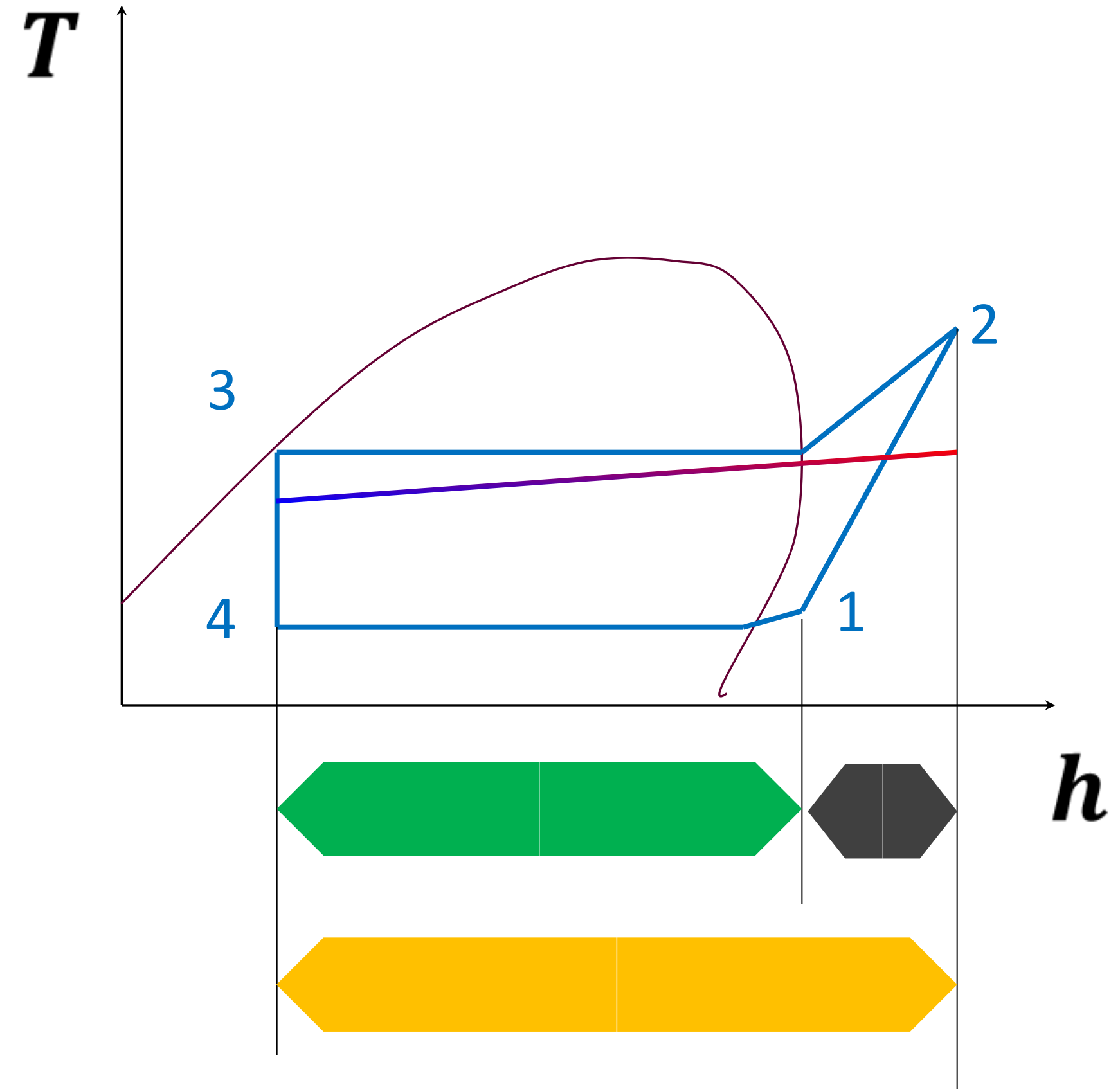


Heat Pump

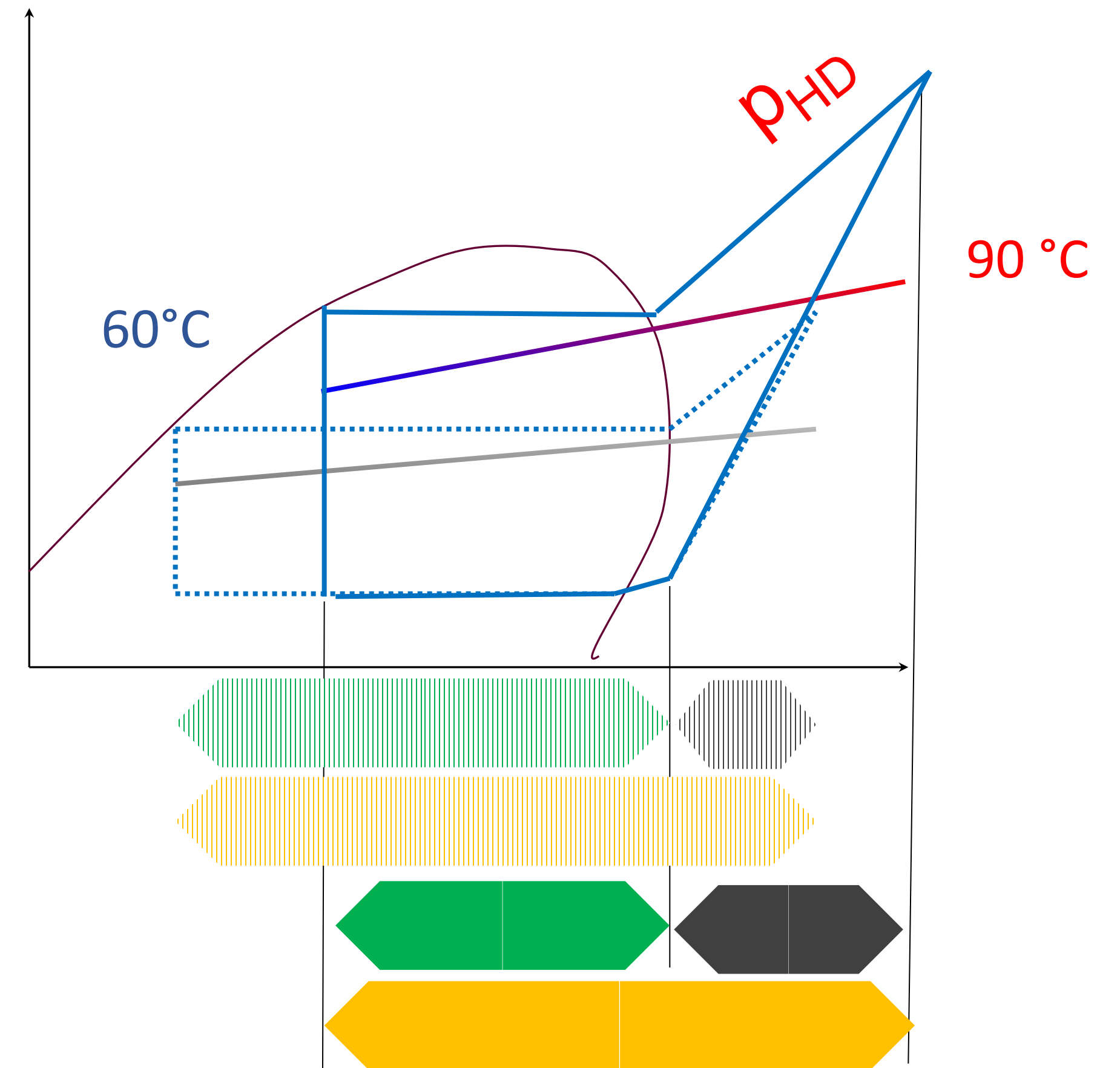
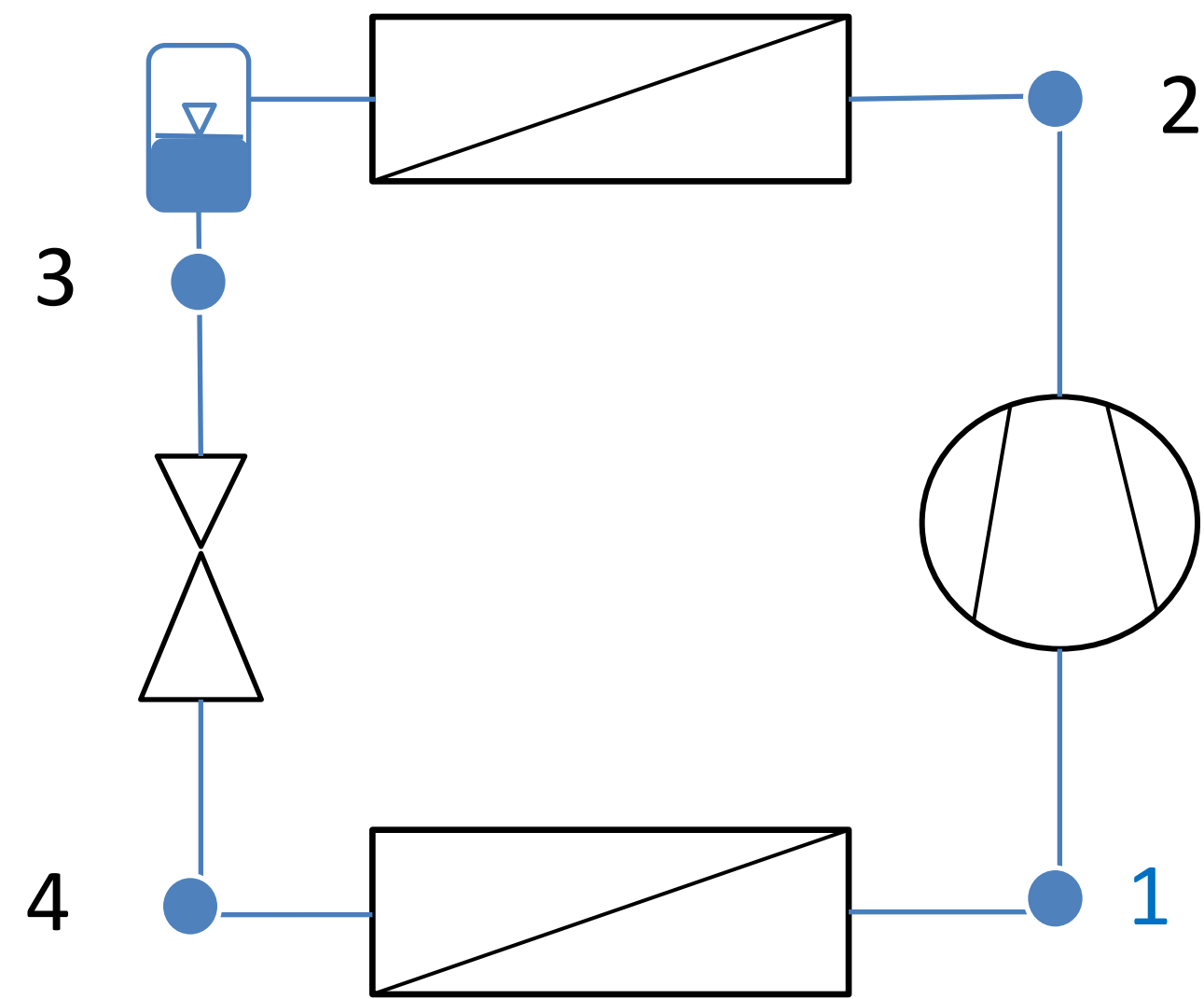
\dot{Q}_{Heat}



$$COP = \frac{\dot{Q}_{Heat}}{P_{el}}$$



Heat Pump



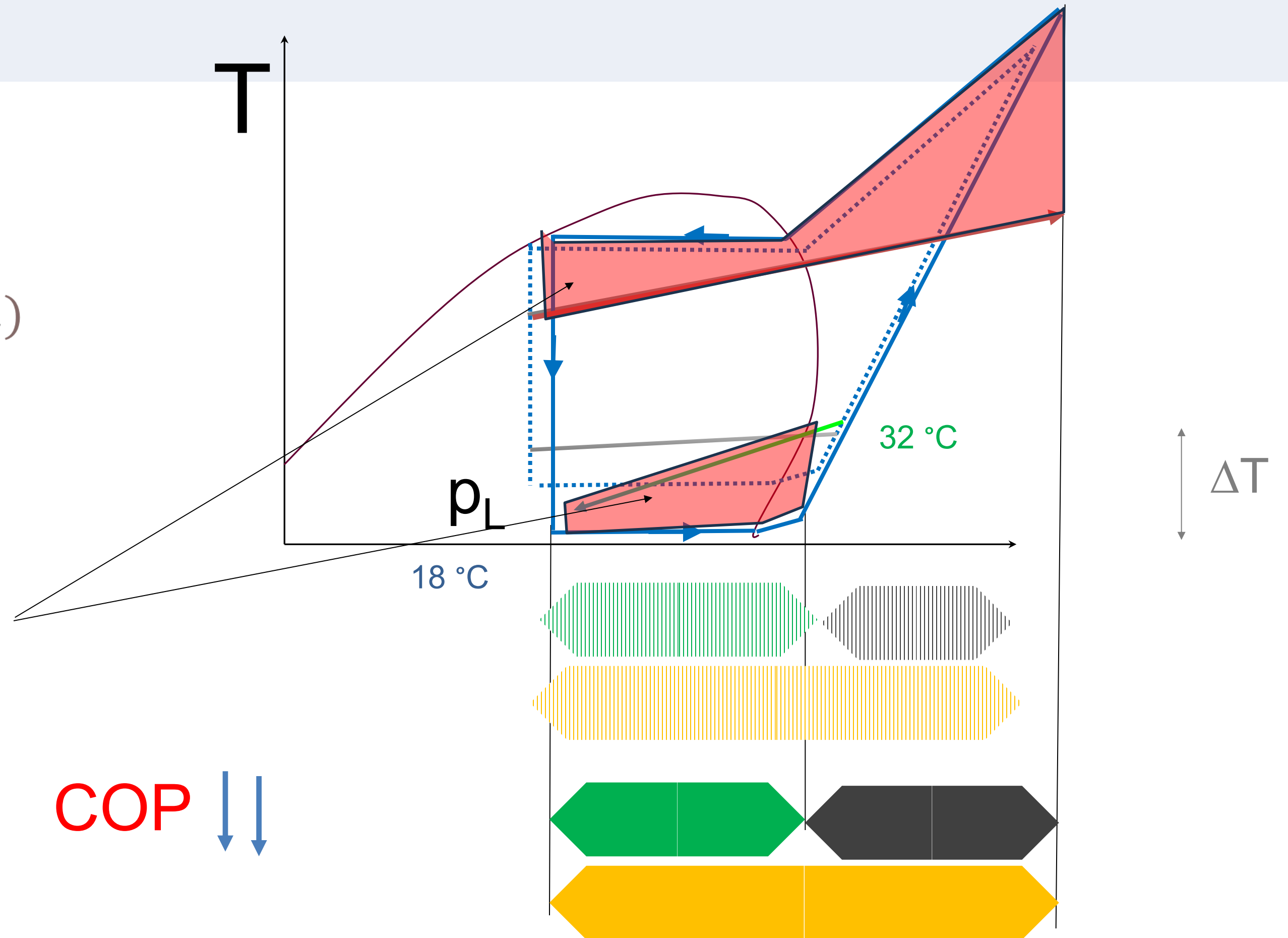
COP ↓

$$\dot{E}x_{loss} = T_{amb}(\dot{m}_{cold} * \Delta S_{cold} - \dot{m}_{hot} * \Delta S_{hot})$$

Gouy-Stodola-
Equation

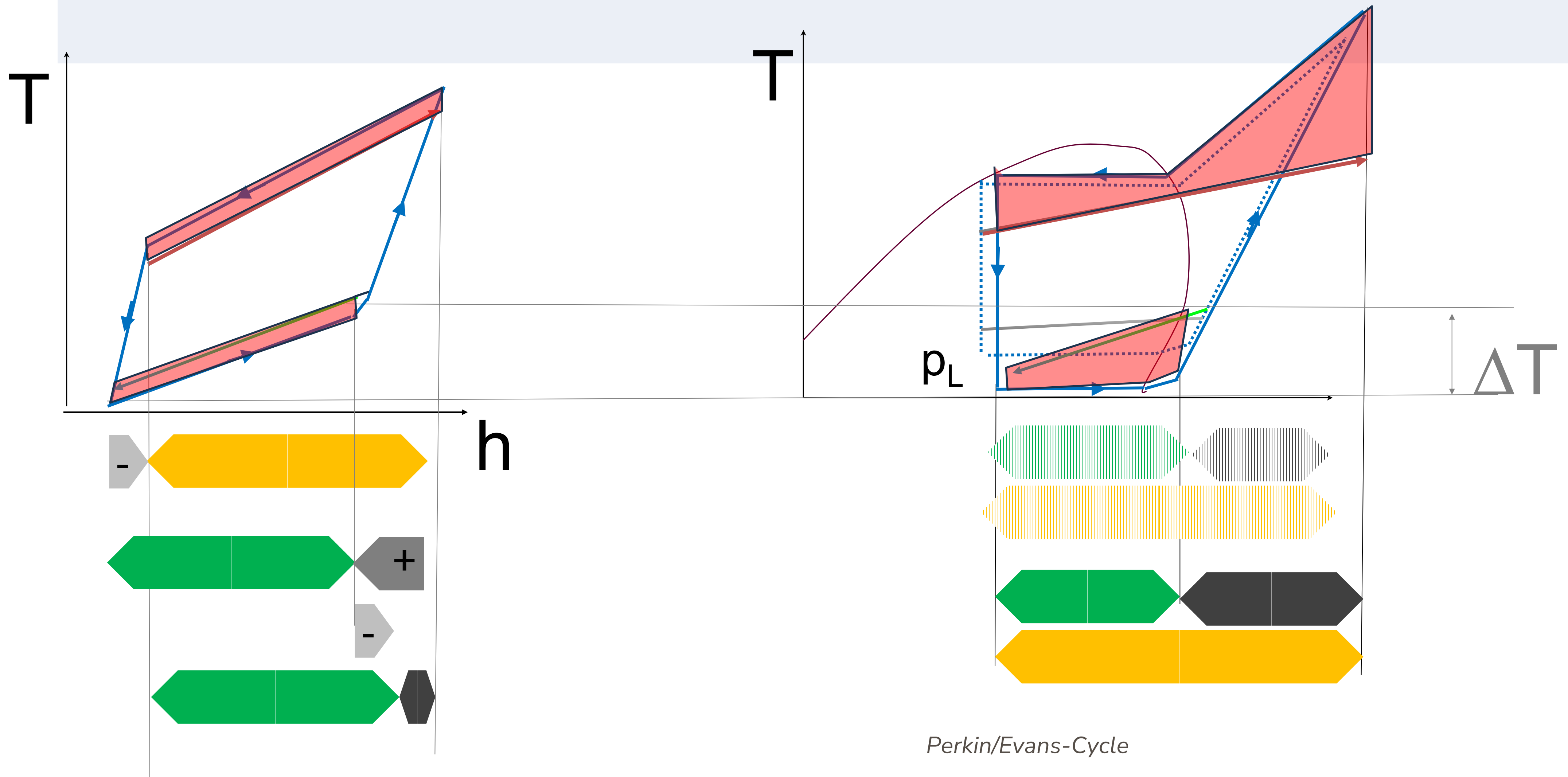
**High
exergetical
losses**

**Exergy losses
have to be paid**



Perkin/Evans-Cycle

Exergie-Analyse



Reverse Joule Cycle –RHP GEN2

Perkin/Evans-Cycle

Perkin/Evans-Cycle

Which cycle fits?

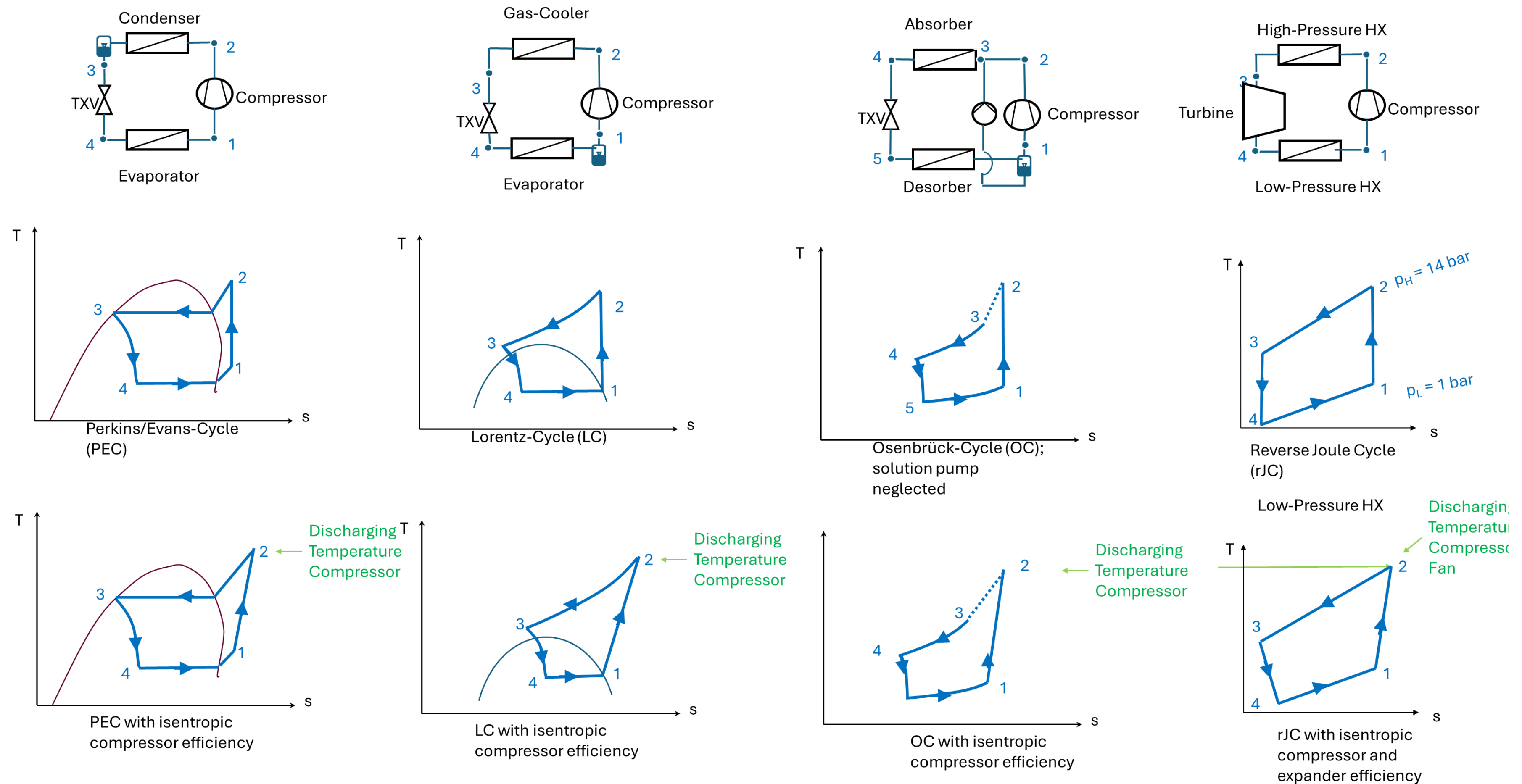
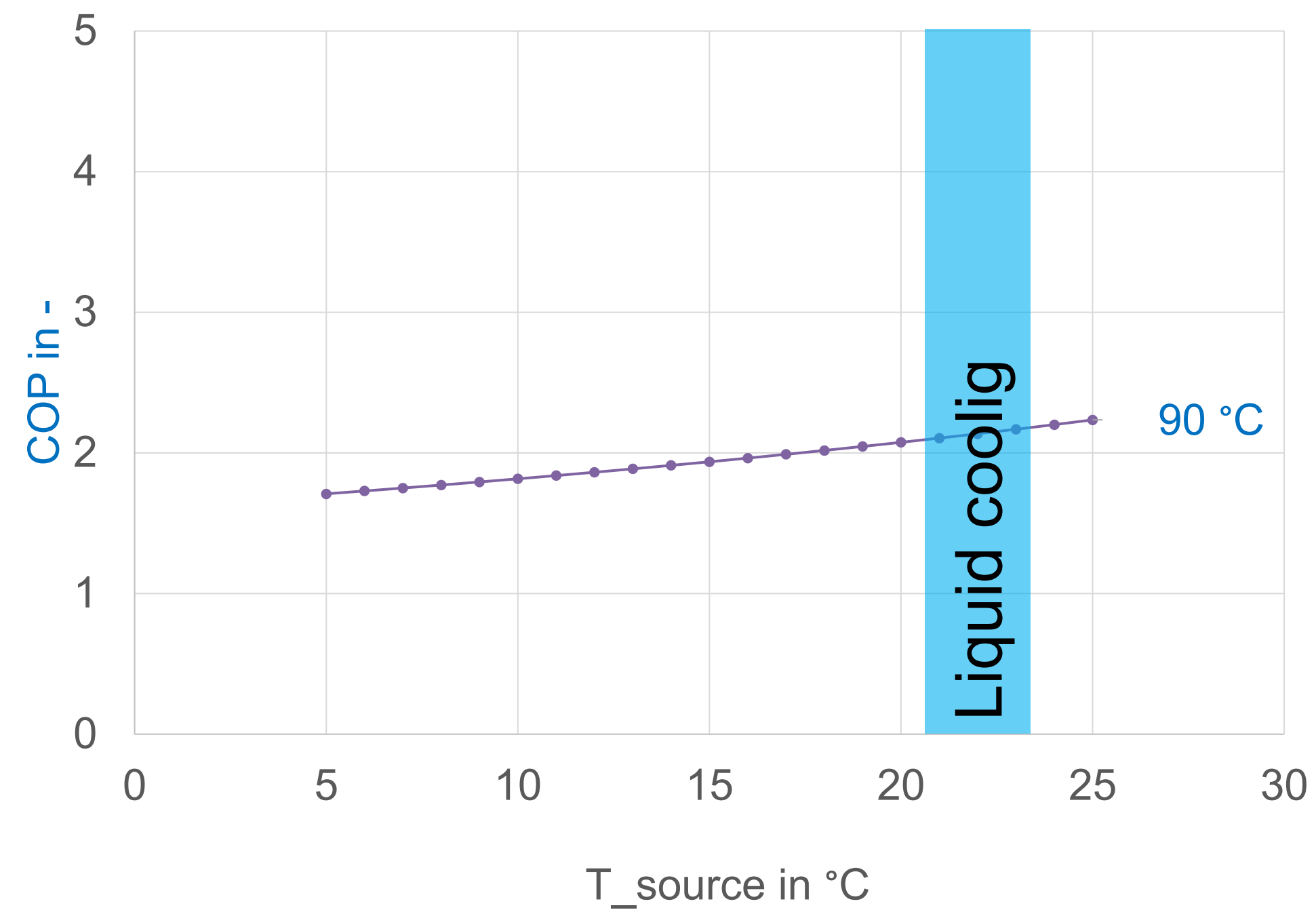


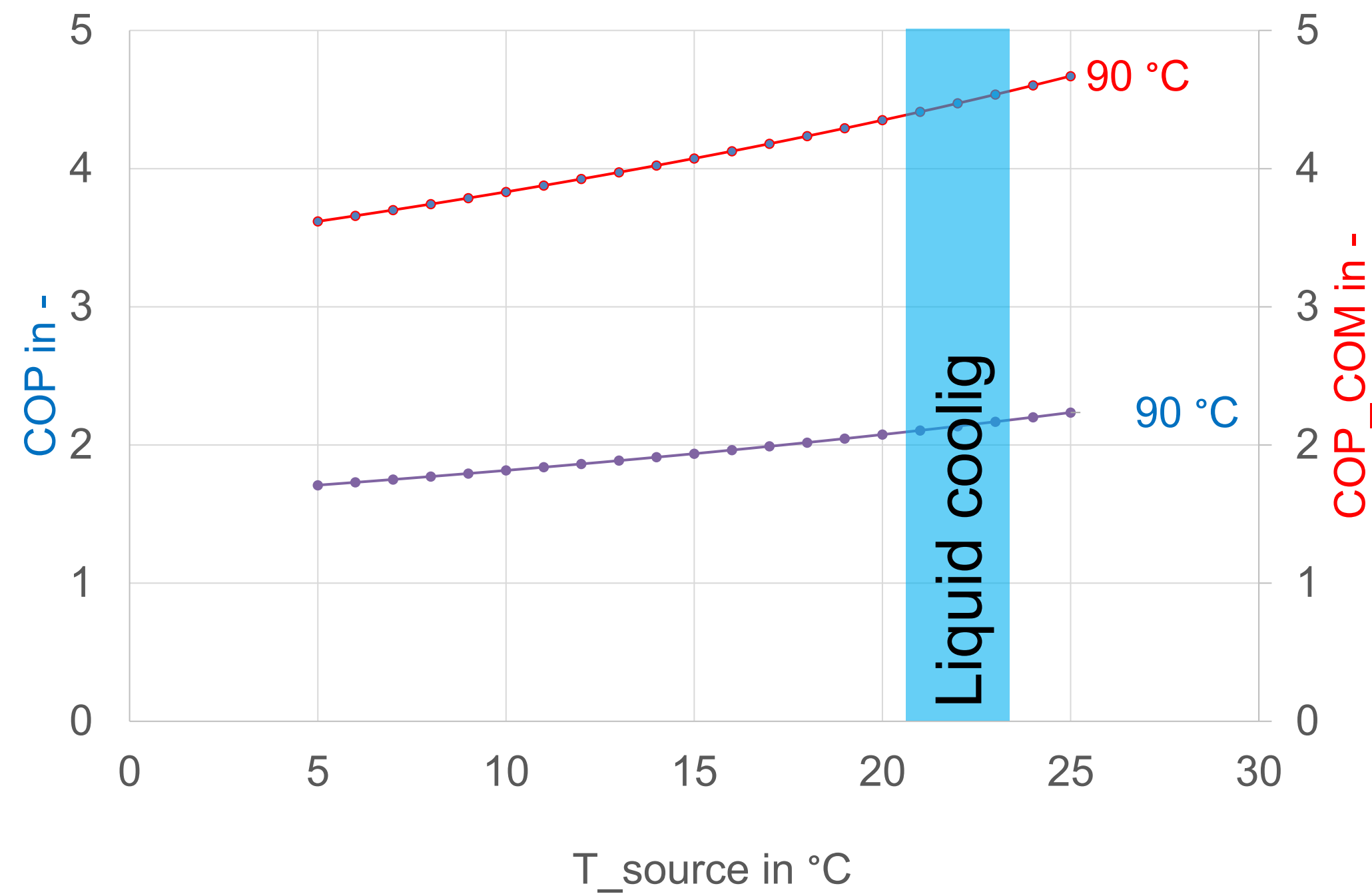
Figure: Overview of heat pump cycles – from left to right – (subcritical) Perkins/Evans cycle [10], Lorentzen (transcritical) cycle [11], Osenbrück cycle [13], reverse (counterclockwise and supercritical) Joule/Brayton cycle (rJC) [10], the reversible Joule cycle in a rotary heat pump (RHP) [14] and the Adler/Zotter/Längauer cycle [9] (Zotter, 2026)

BI-Generation with liquid cooling



PUE = 1.6

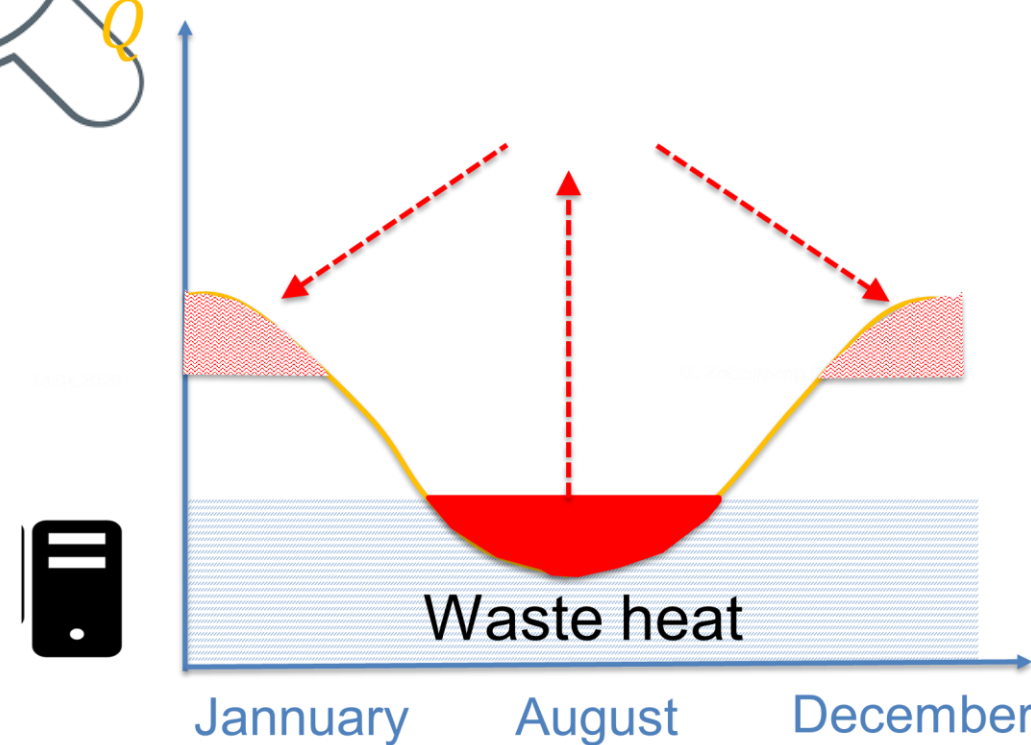
BI-Generation with liquid cooling



PUE = 1.6
ERF = 0.8
ERE = 0.3



Investigate of location of data centers (close to DH-grids?)



Analyse the overlap of temporally heat requirement

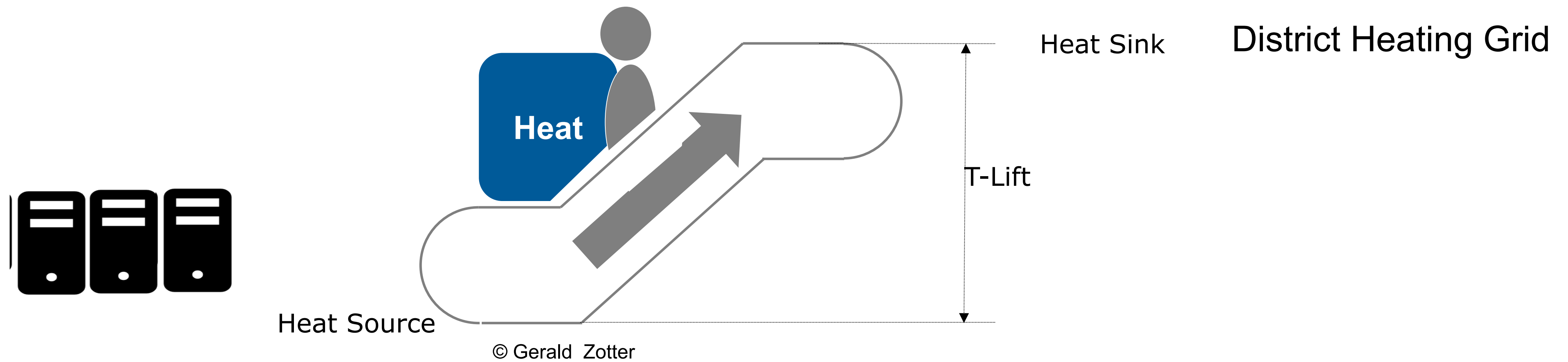


High temperature heat pumps are key



Cost saving by using high temperature waste heat

Heat pump: “Temperature elevator”



An aerial photograph of a modern building complex. The buildings feature large glass facades and solar panels. A central courtyard with a paved walkway and greenery is visible. The sky is clear and blue.

AEE INTEC

IDEA TO ACTION

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Gerald Zotter
g.zotter@aee.at

Economic analysis: High Temperature Heat Pumps about 500 to 1000 € per kW

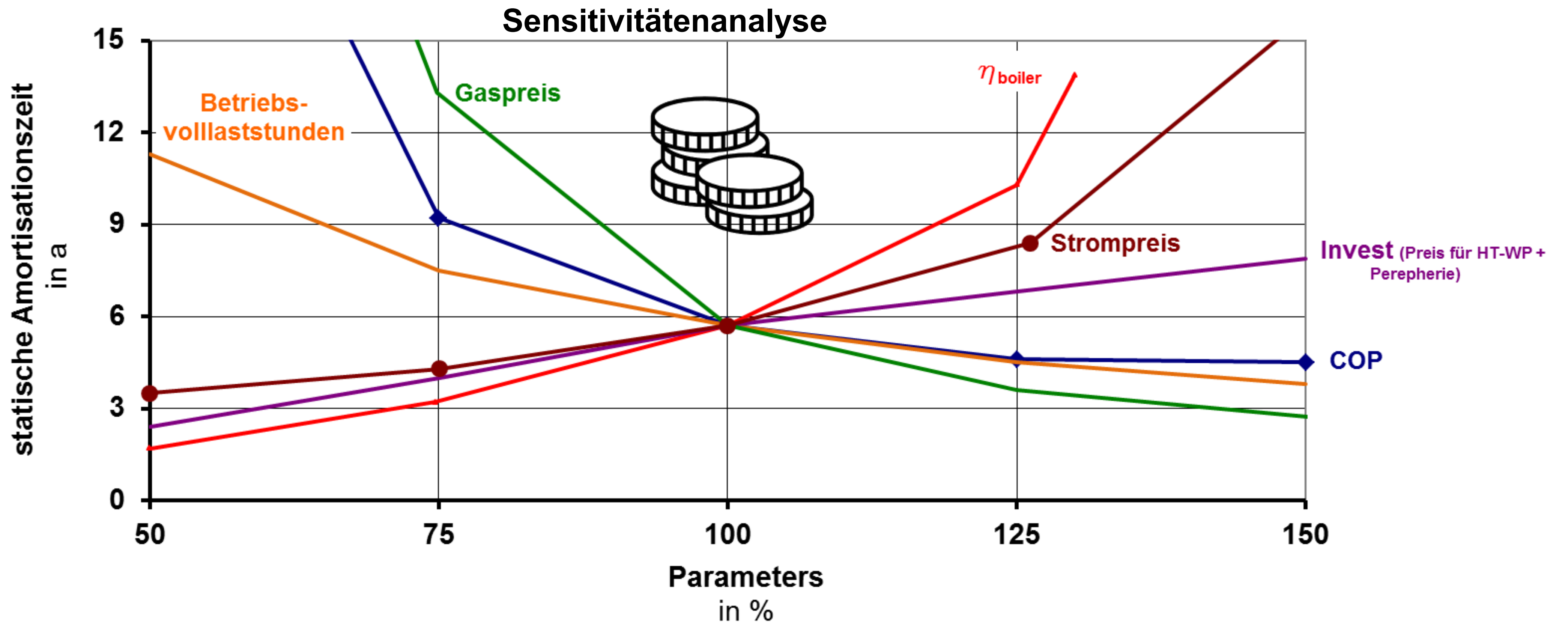


Figure: Sensitivity analysis via high-temperature heat pump in electroplating operation (Zotter, Rieberer 2014)

⇒ **The decision for / against INVEST is mostly determined by the ROI!**

