Chiller Control

Friday Seminar 2022-03-04
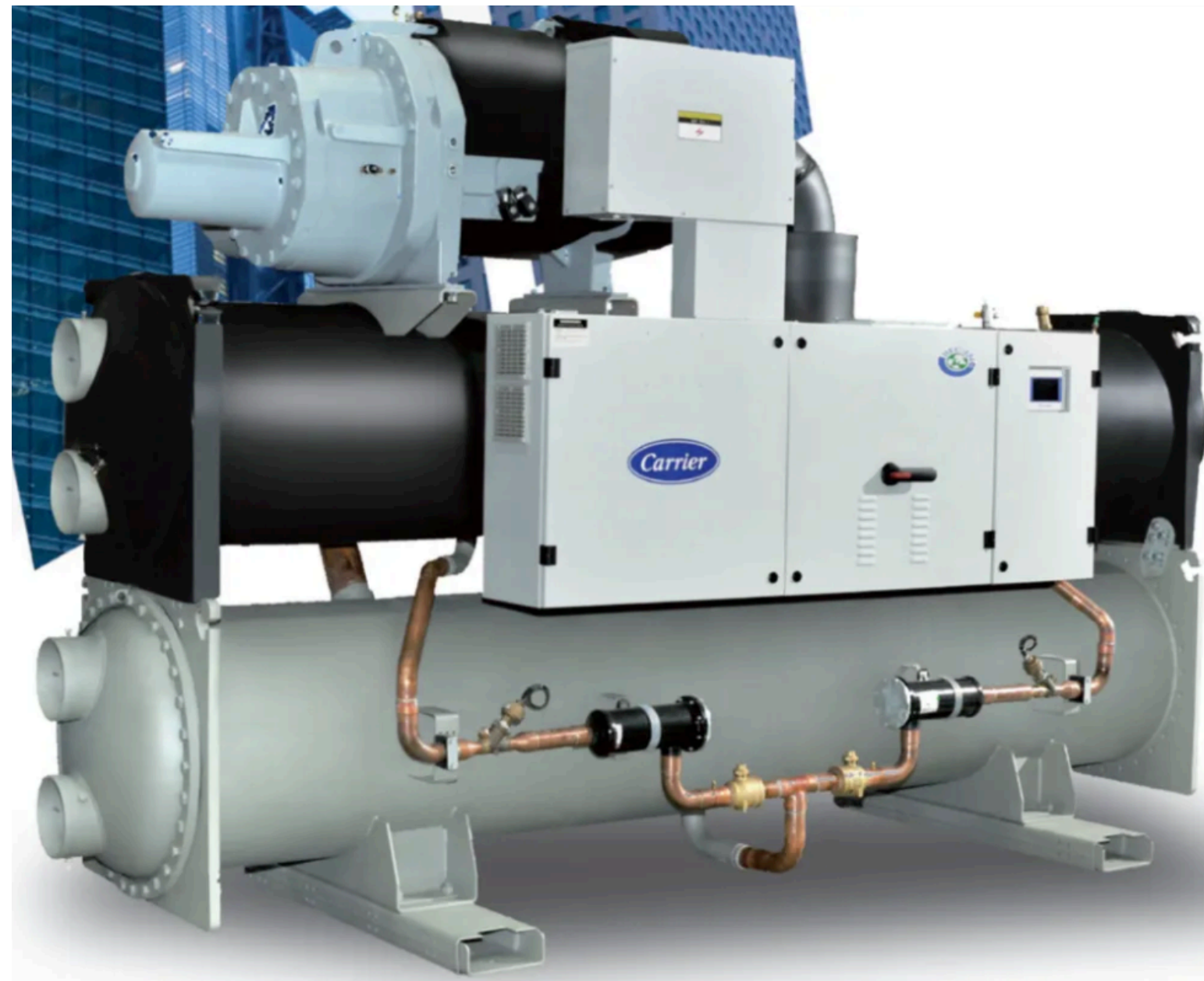Christian Rosdahl

Chiller control

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Cooperation with Carrier

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Willis Carrier (1876–1950)

Invented modern air conditioning in 1902.

Founded the company in 1915, with six other engineers.

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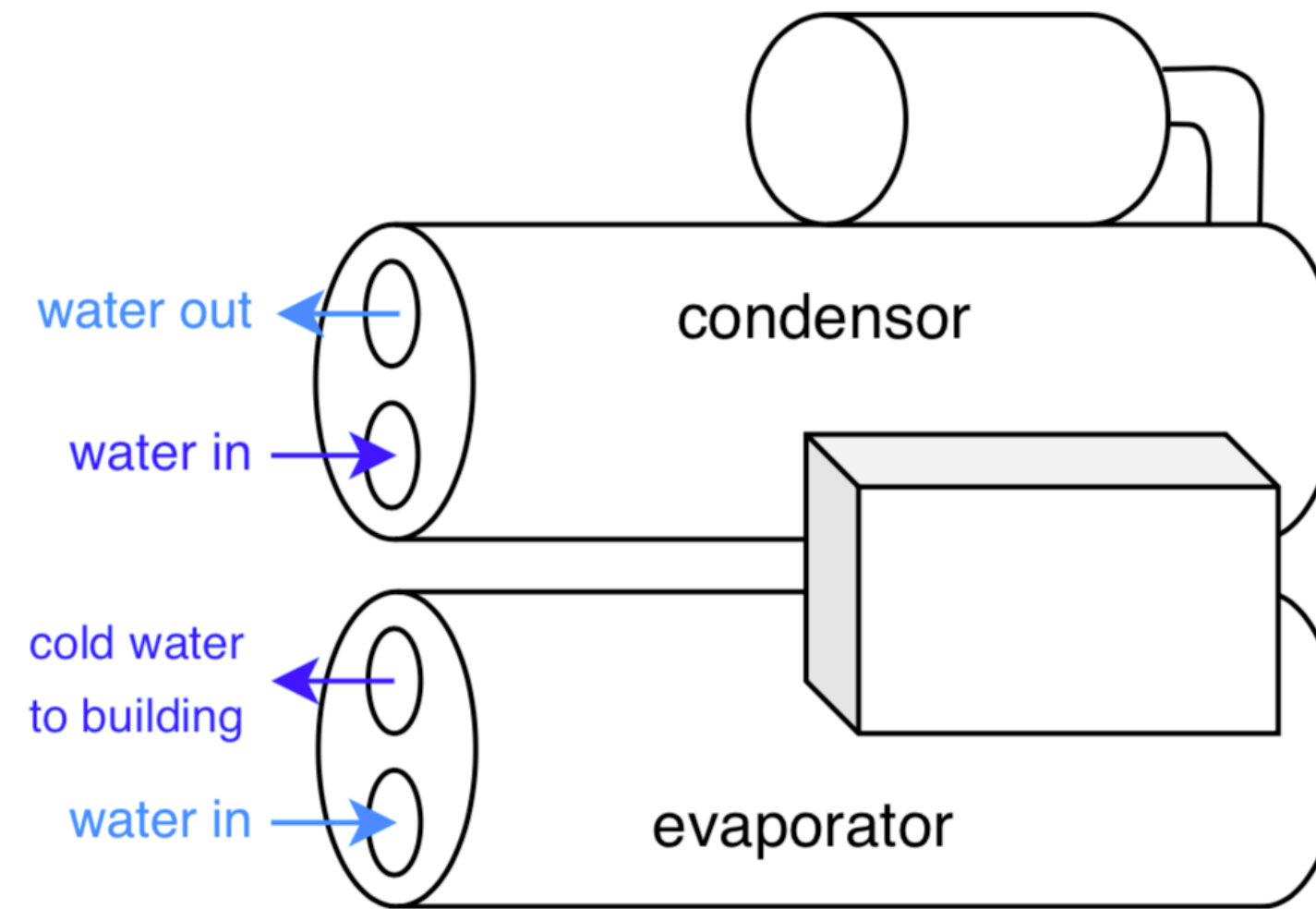

Thanks to
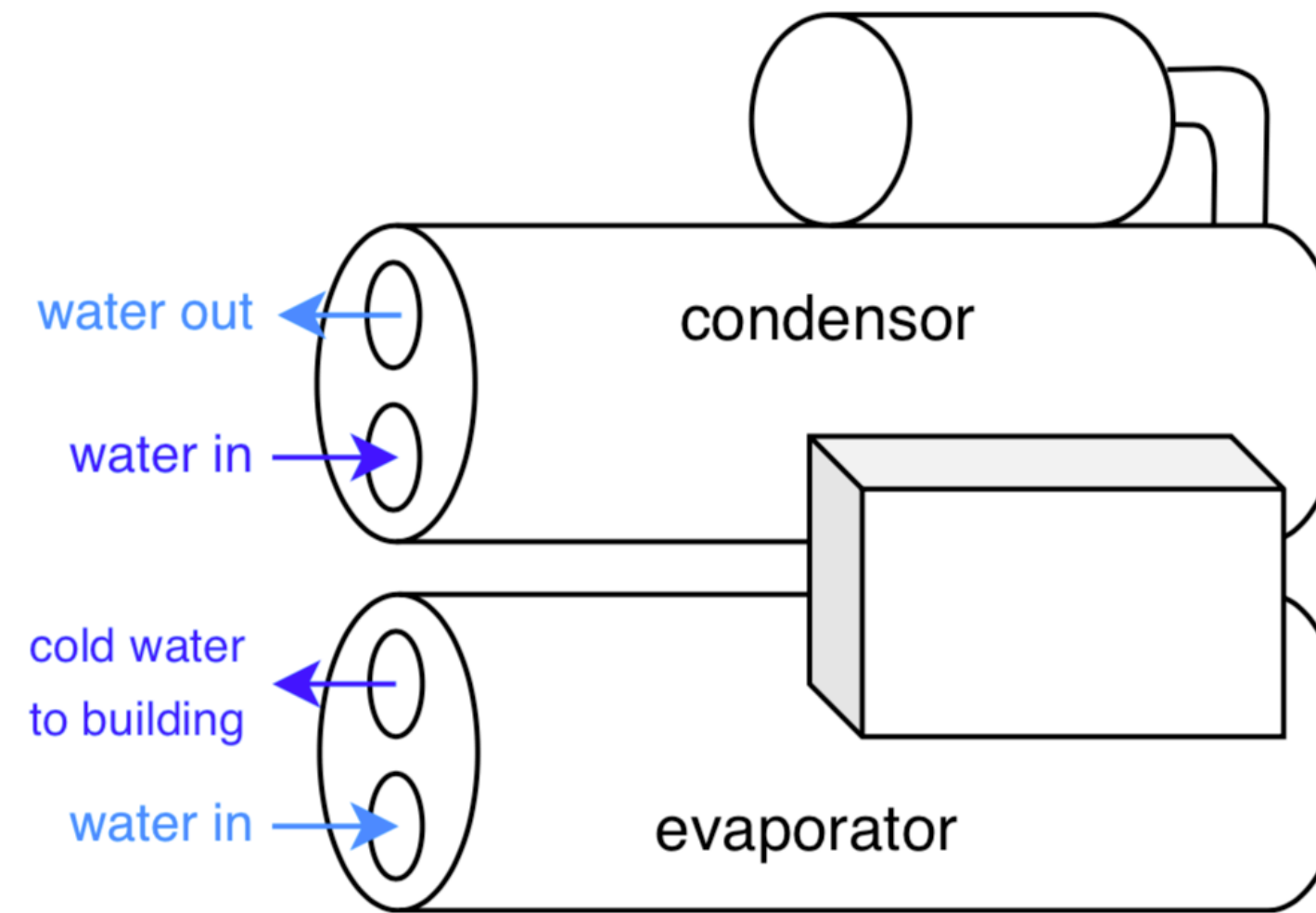Bryan Eisenhower, Magda Atlevi and Clas Jacobson @ Carrier

What is a chiller?

What is a chiller?

water out

water in

condensor

cold water
to building

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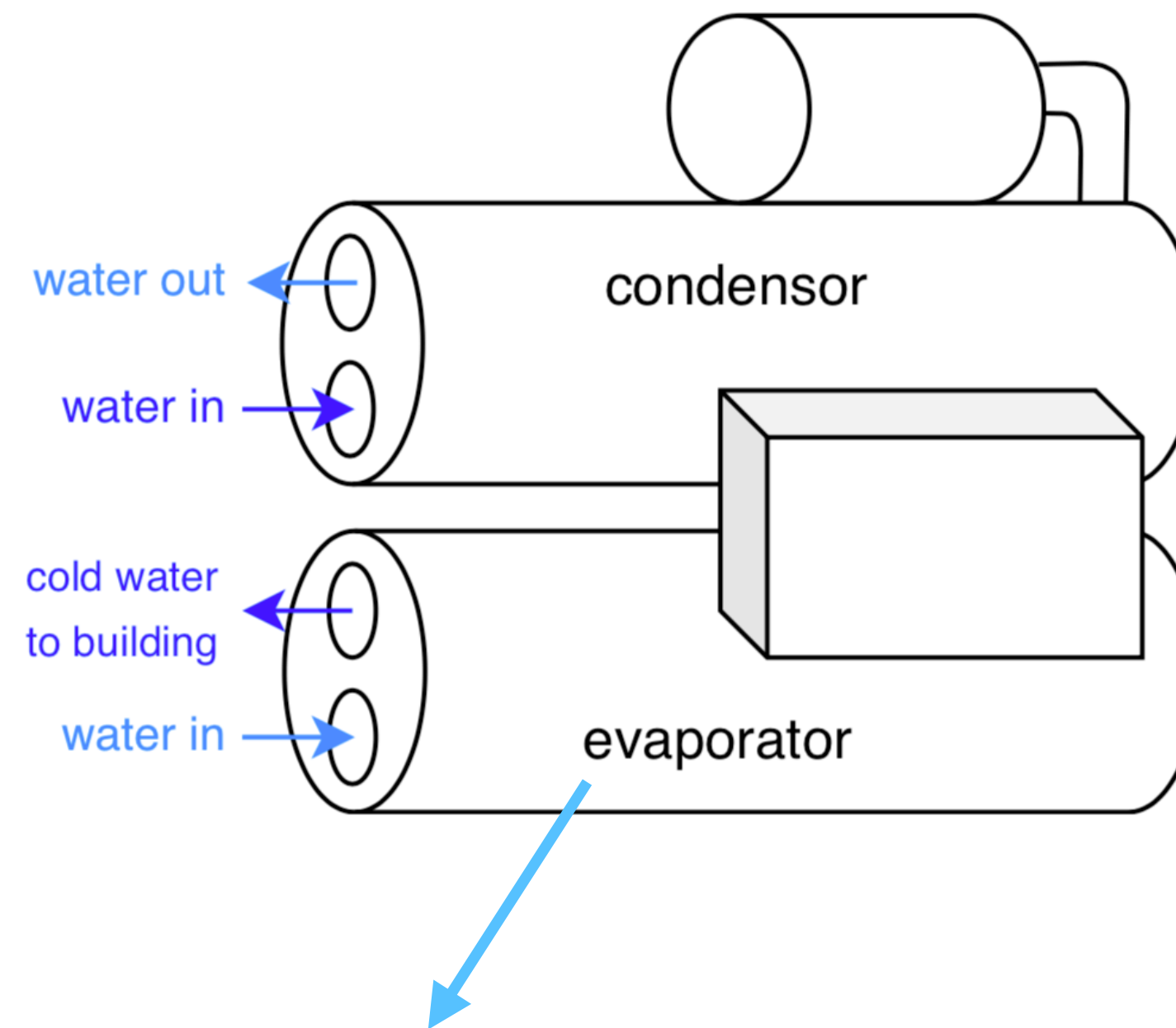
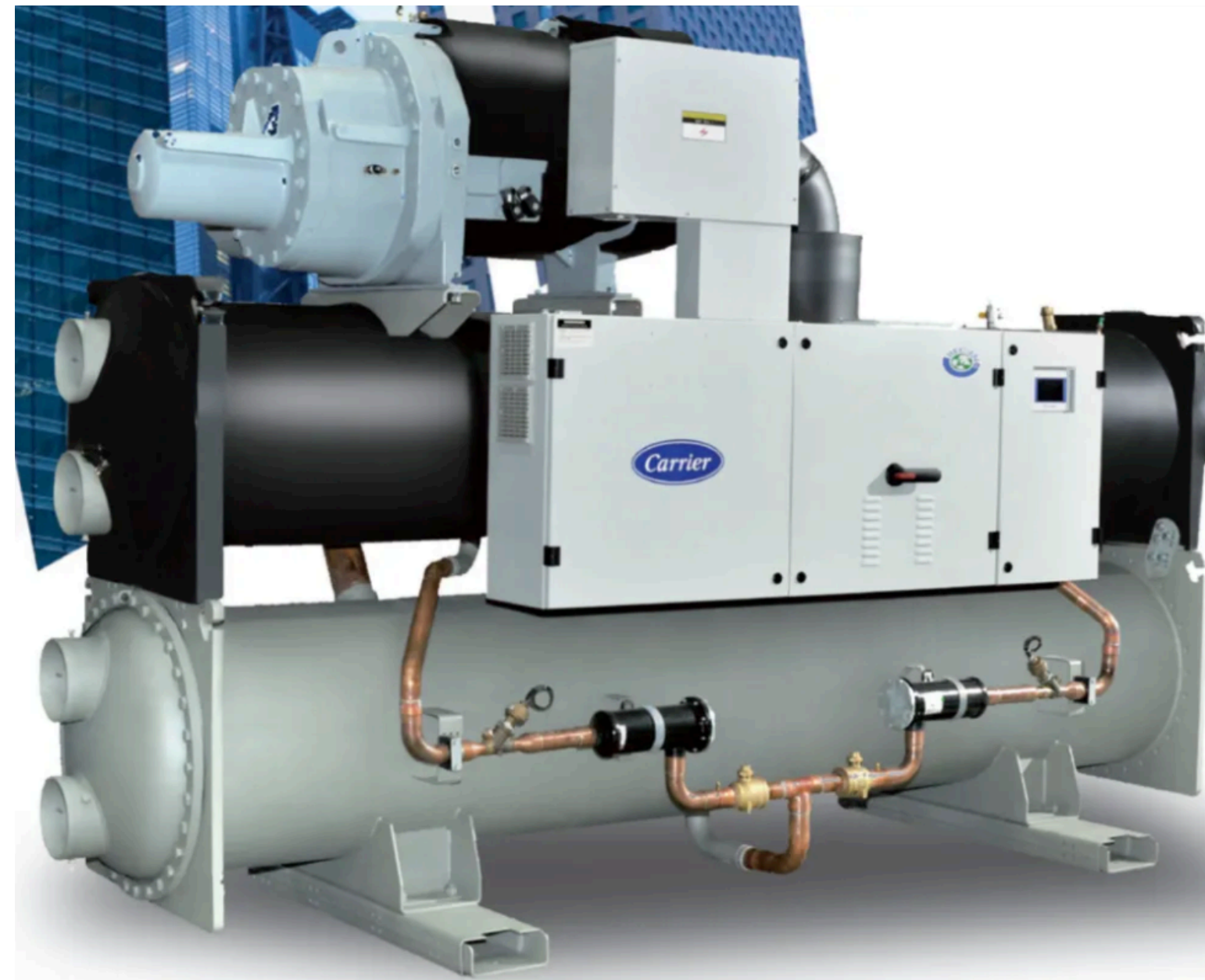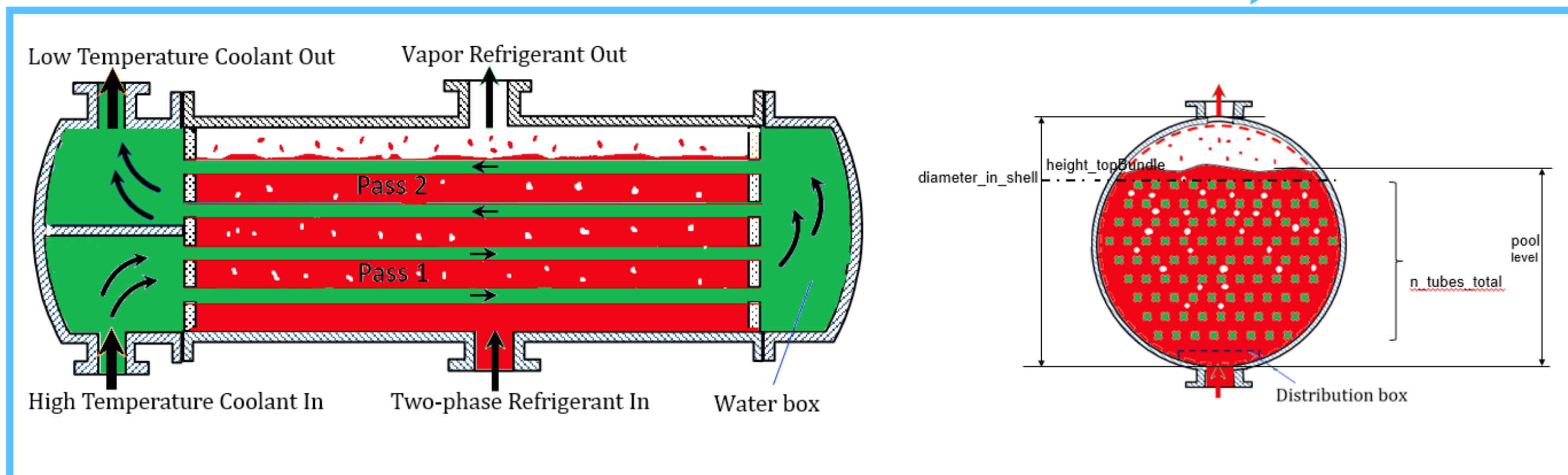# What is a chiller?

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Low Temperature Coolant Out
Vapor Refrigerant Out
Pass 2
Pass 1
High Temperature Coolant In
Two-phase Refrigerant In
Water box

diameter_in_shell
height_topBundle
pool level
n_tubes_total
Distribution box

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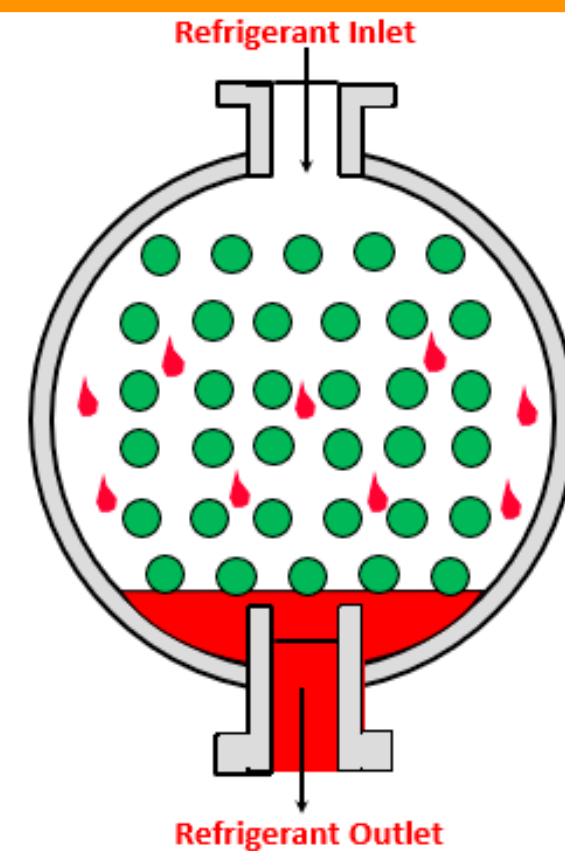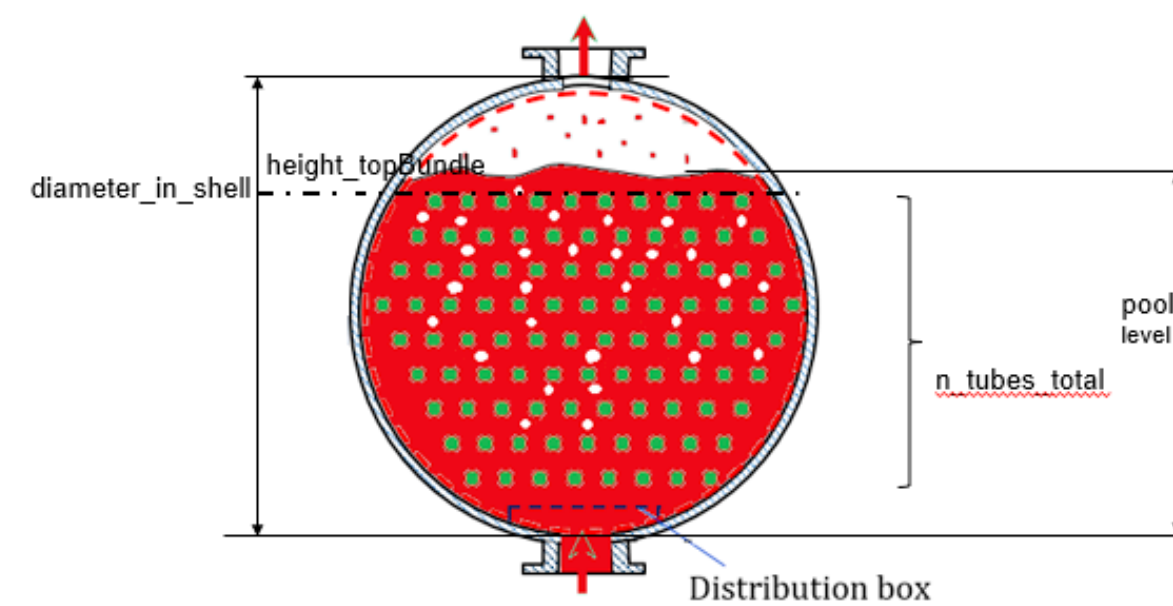
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Refrigerant Inlet

High Temperature Coolant Outlet

Vapor Refrigerant Inlet

Low Temperature Coolant Inlet

Liquid Refrigerant Outlet

Refrigerant Outlet

Energy consumption

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— *International Energy Agency, IEA*

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Space cooling consumes about 1885 TWh per year, which is **about 8% of the world's total electricity consumption**. [1,2]

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Question: Can we improve the efficiency by using machine learning methods?

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Some thermodynamics

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= thermodynamical potential

$$H = U + pV$$

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inner energy   pressure

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heat

constant

temperature

* if there is no phase change

Some thermodynamics

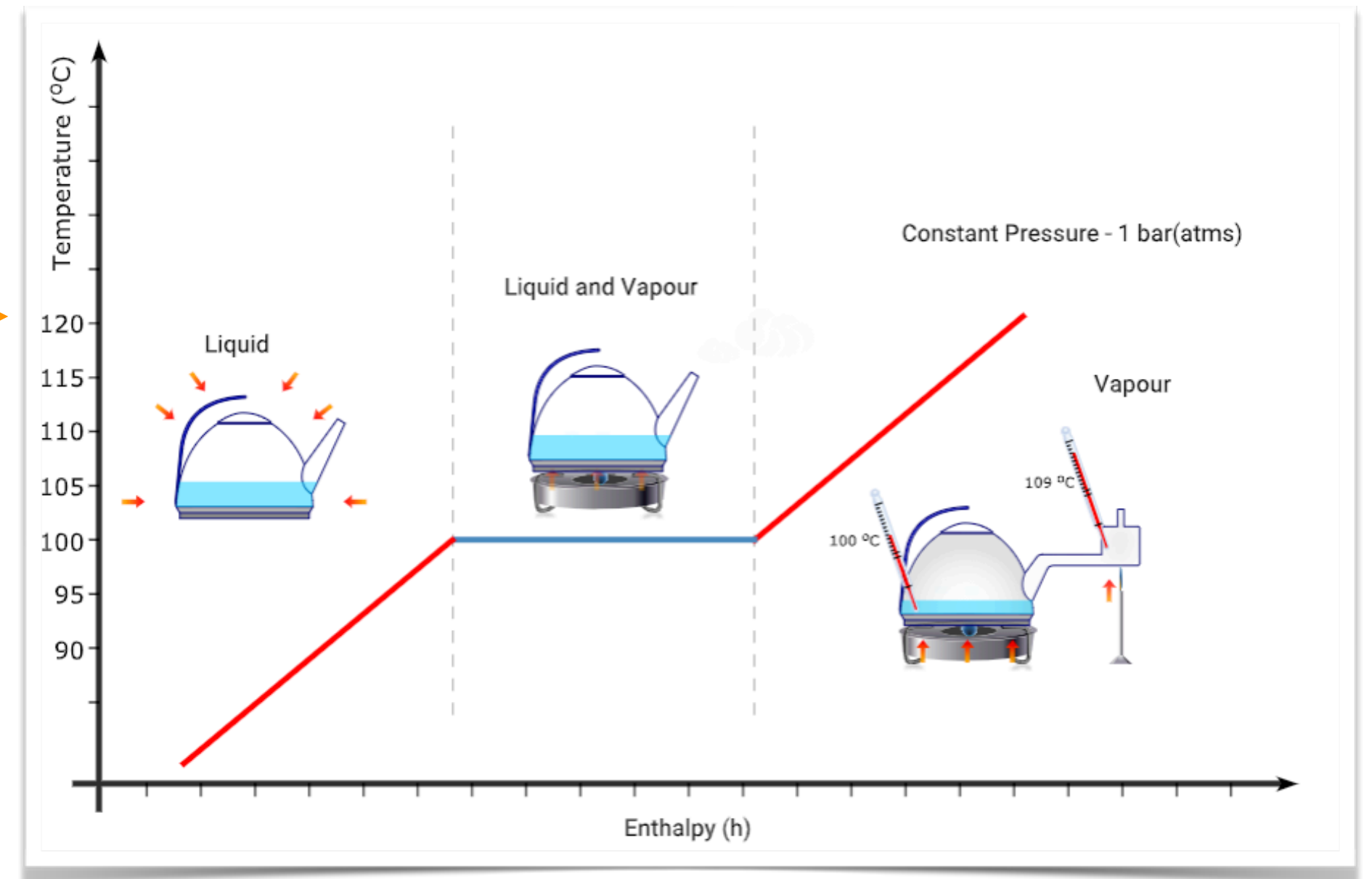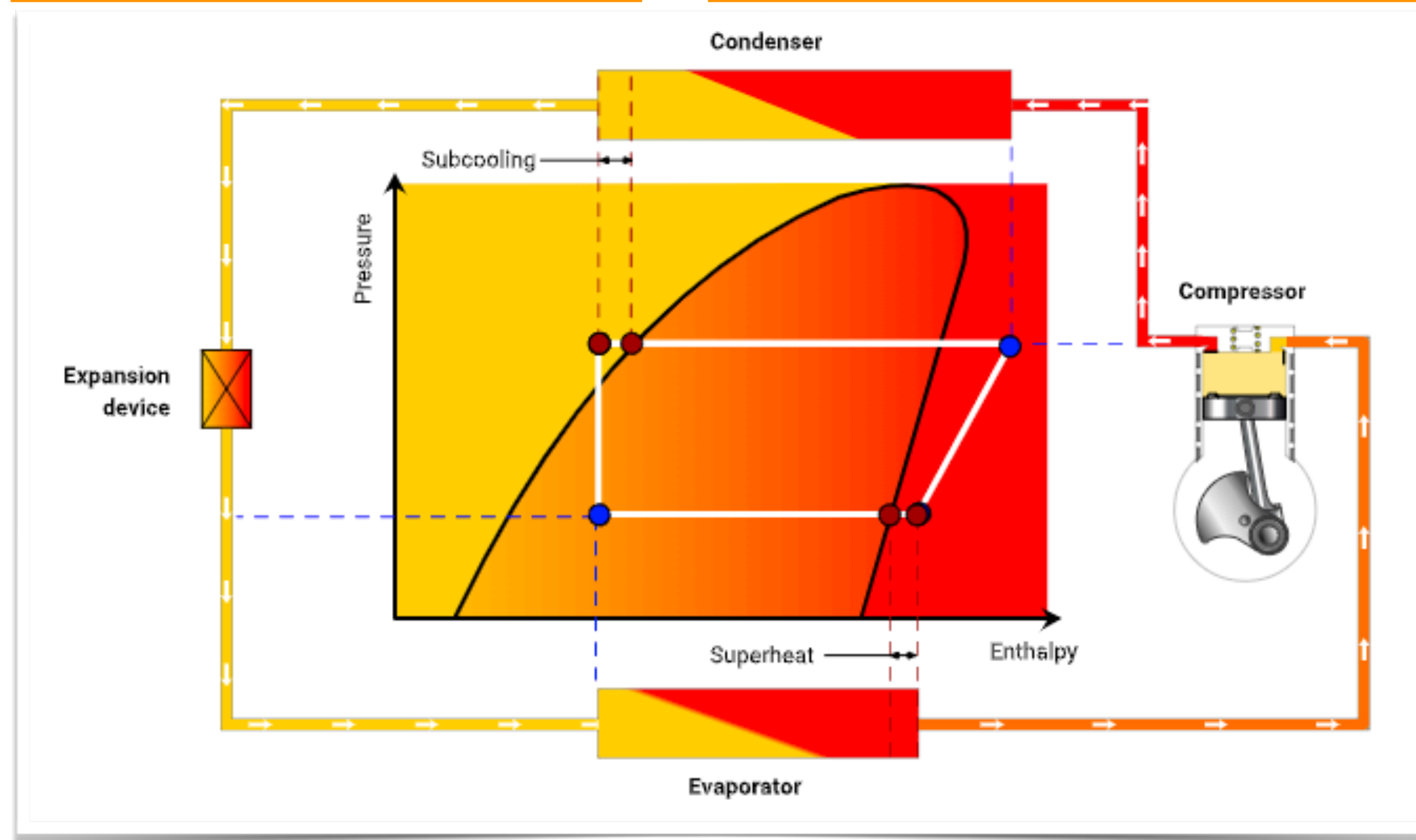Definition: **Enthalpy**

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Constant Pressure - 1 bar(atms)

Temperature (°C)

Liquid — Liquid and Vapour — Vapour

120
115
110
105
100
95
90

Enthalpy (h)

Pressure

Saturation curve

Liquid

Vapour fraction

0 %   50 %

Enthalpy

p-h diagram

Refrigerant cycle

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Refrigerant cycle

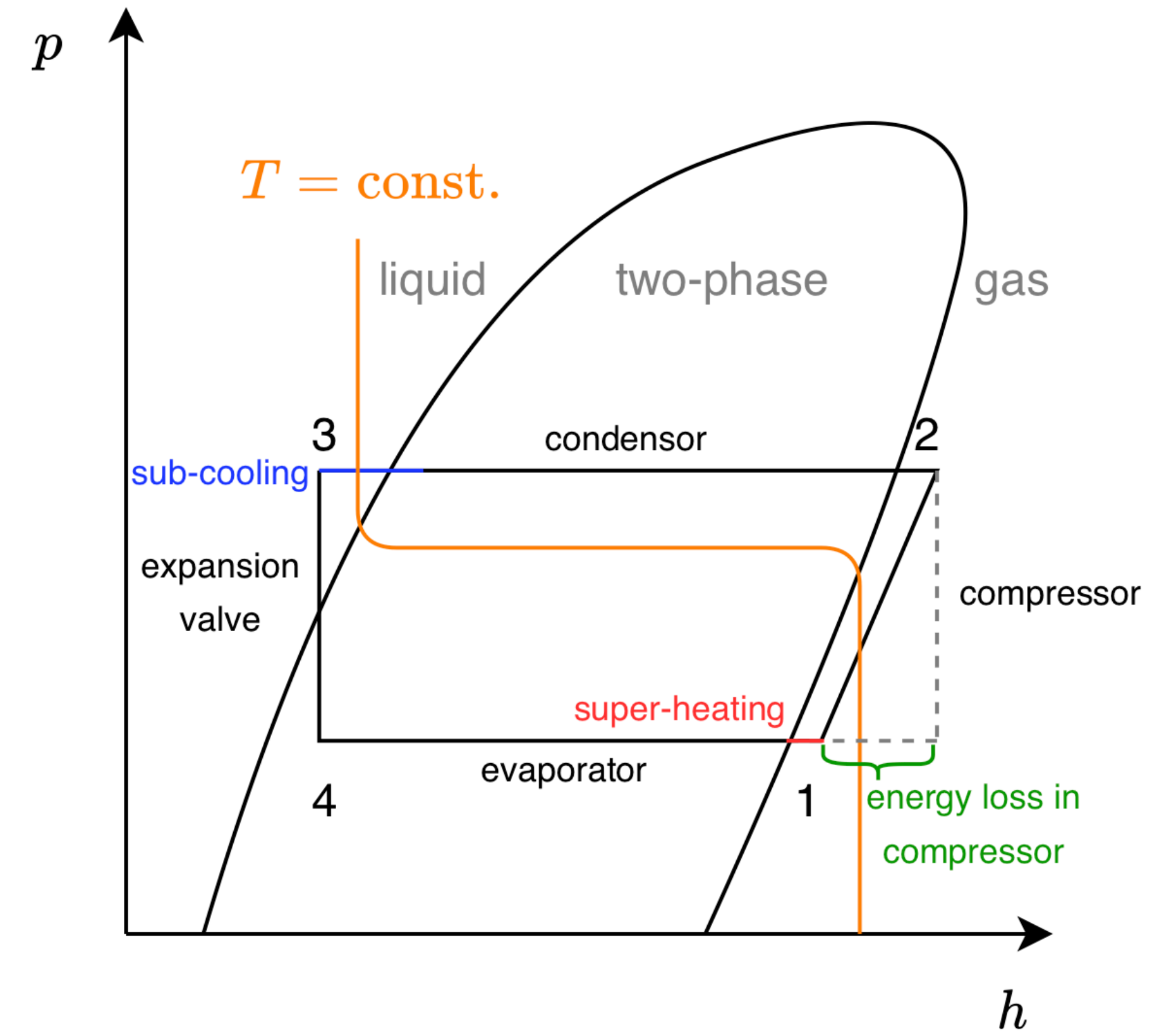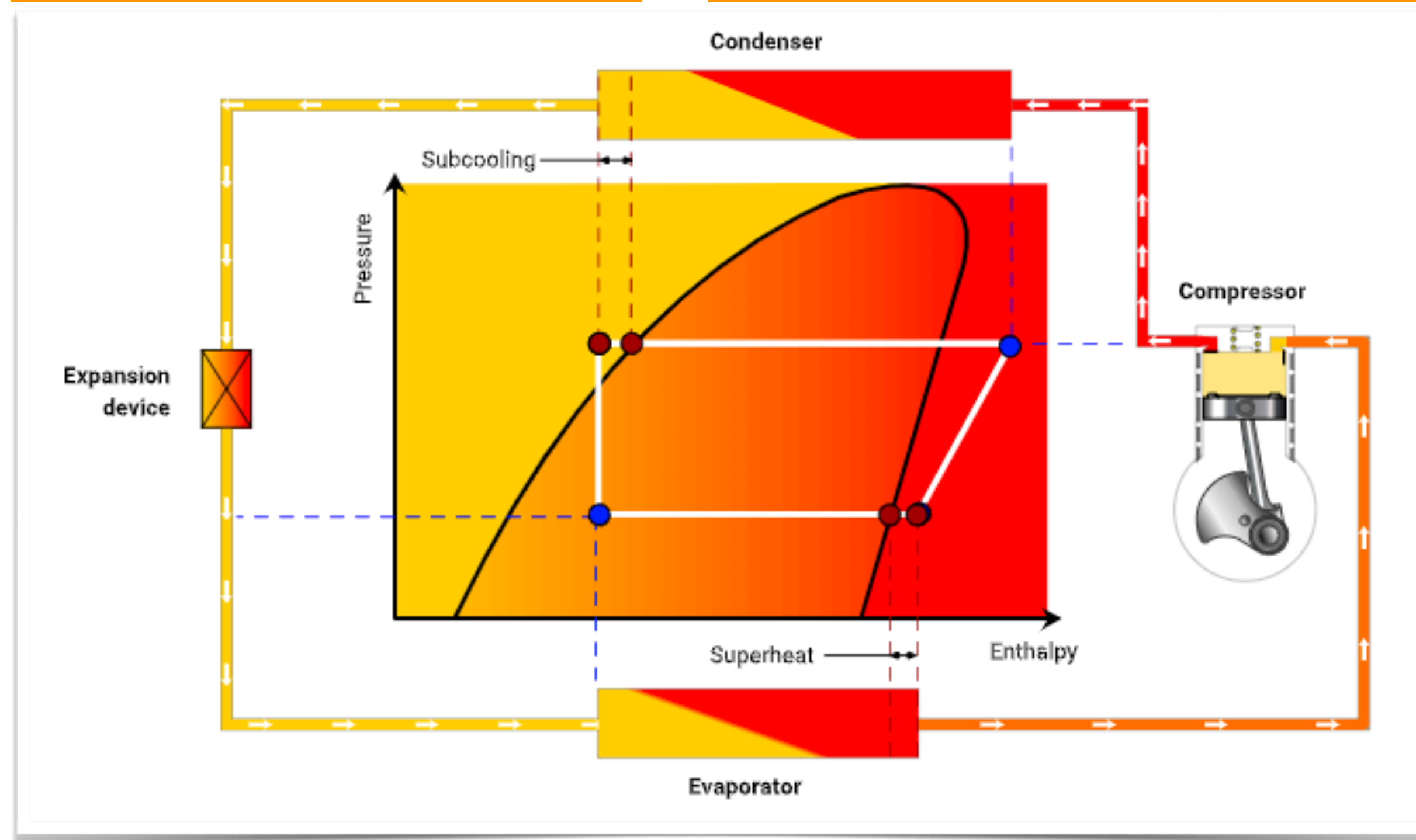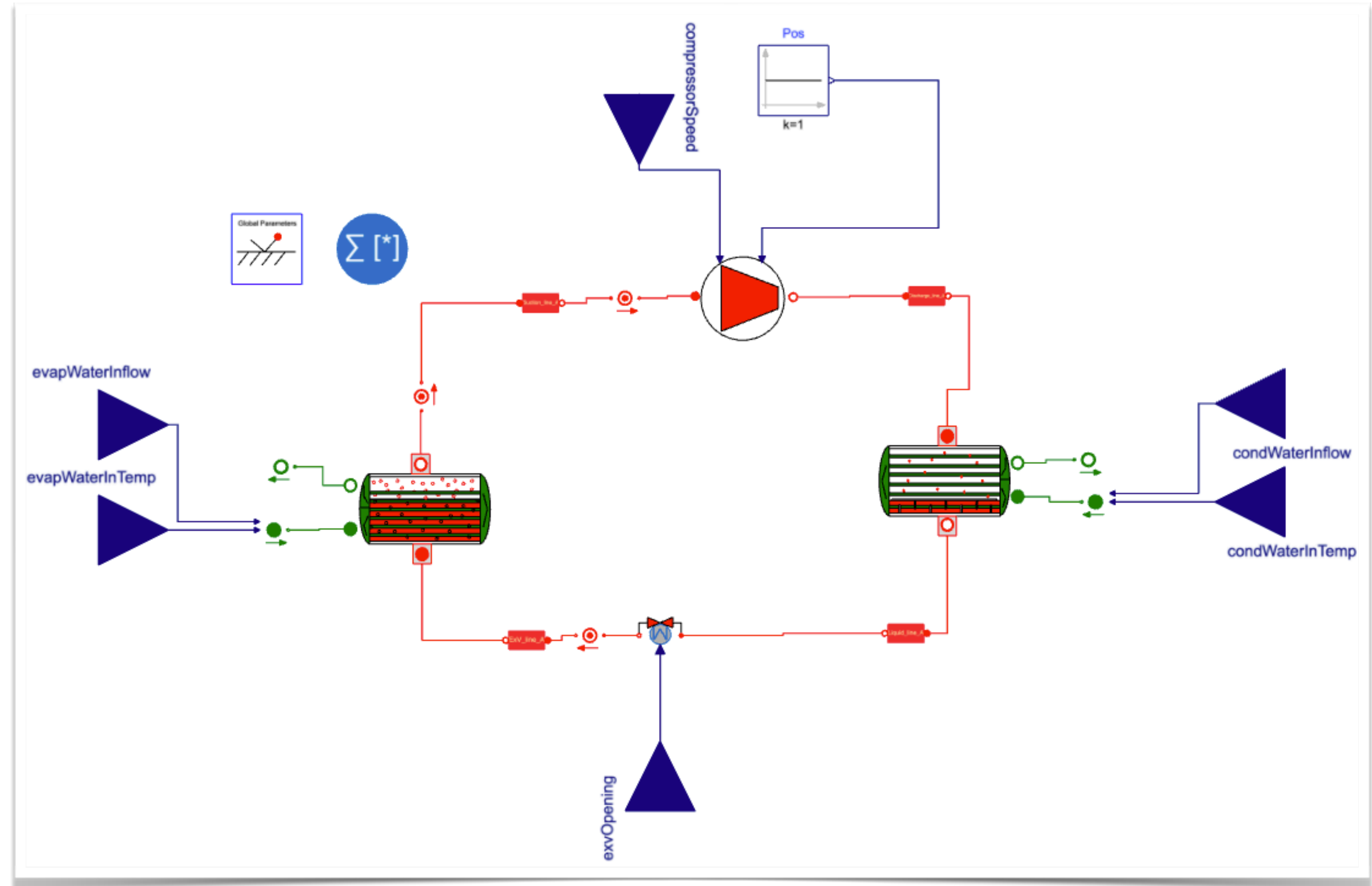Definition: **Enthalpy**

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p

$T = \mathrm{const.}$

liquid   two-phase   gas

3   condensor   2

sub-cooling

expansion valve

super-heating

compressor

evaporator

4   1   energy loss in compressor

h

Condenser

Subcooling

Pressure

Expansion device

Compressor

Superheat   Enthalpy

Evaporator

Simulation model

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Complex nonlinear model, with 161 states.

Simulations can be done in Modelon Impact or in Python with an FMU.

Control problem

Control problem

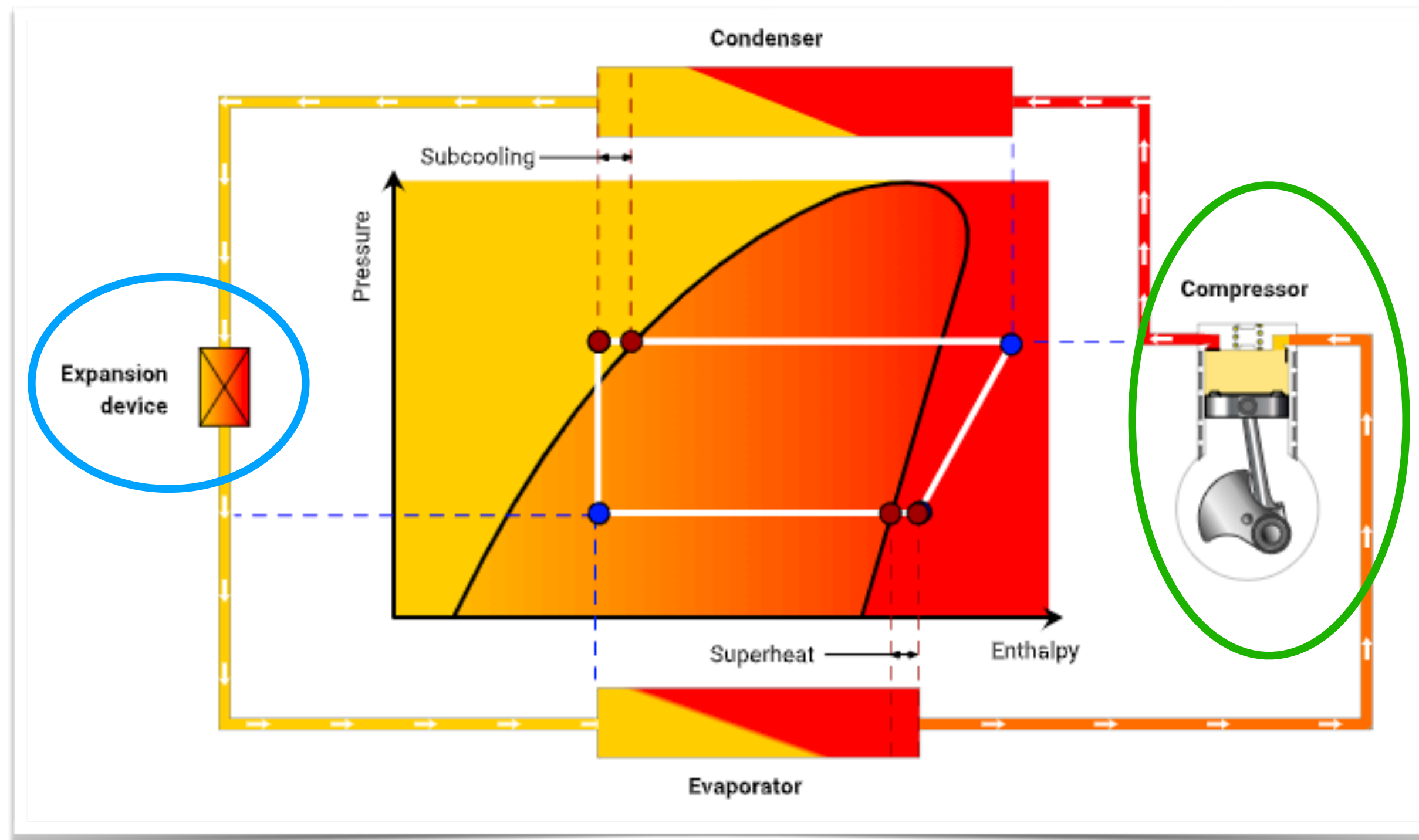# Control problem

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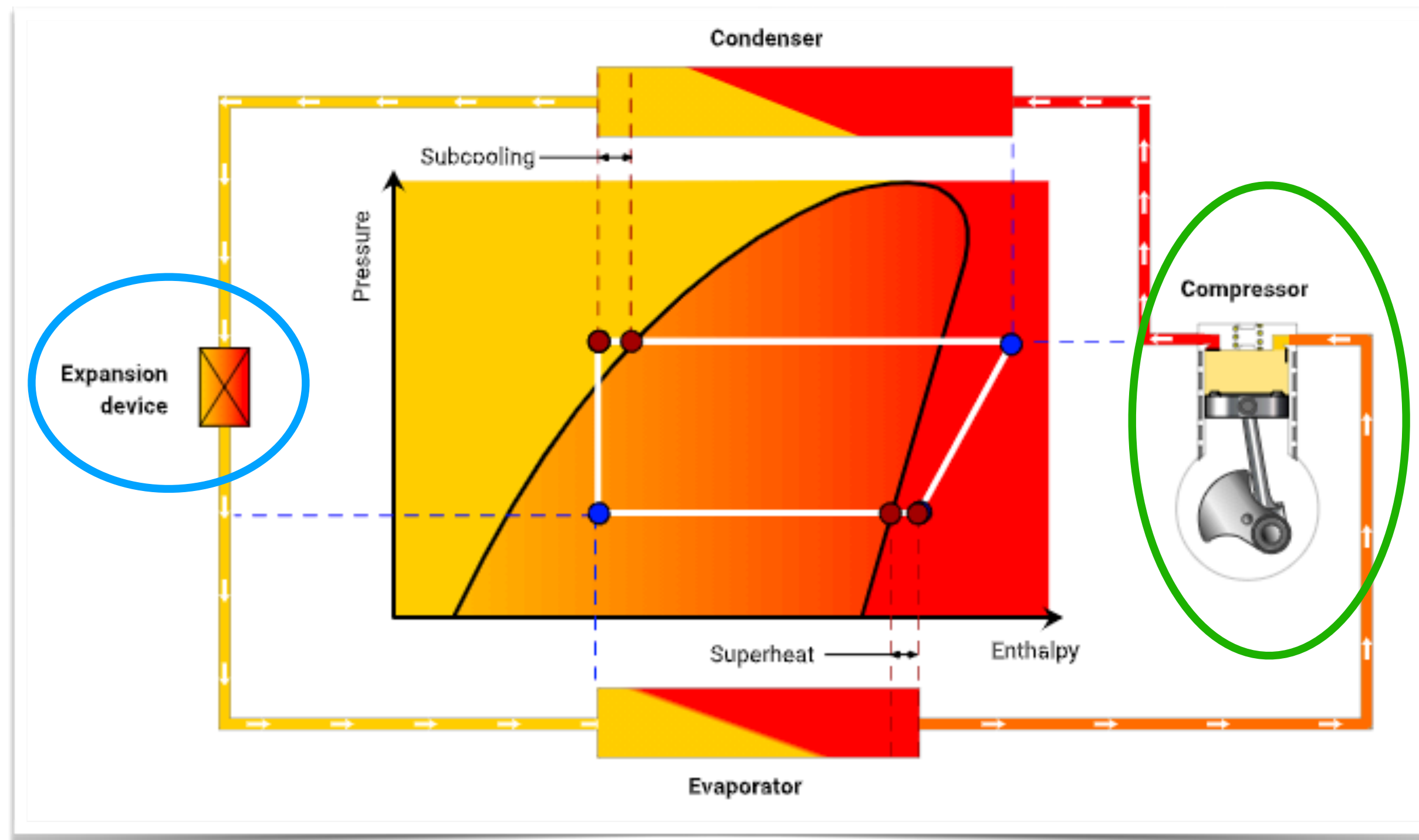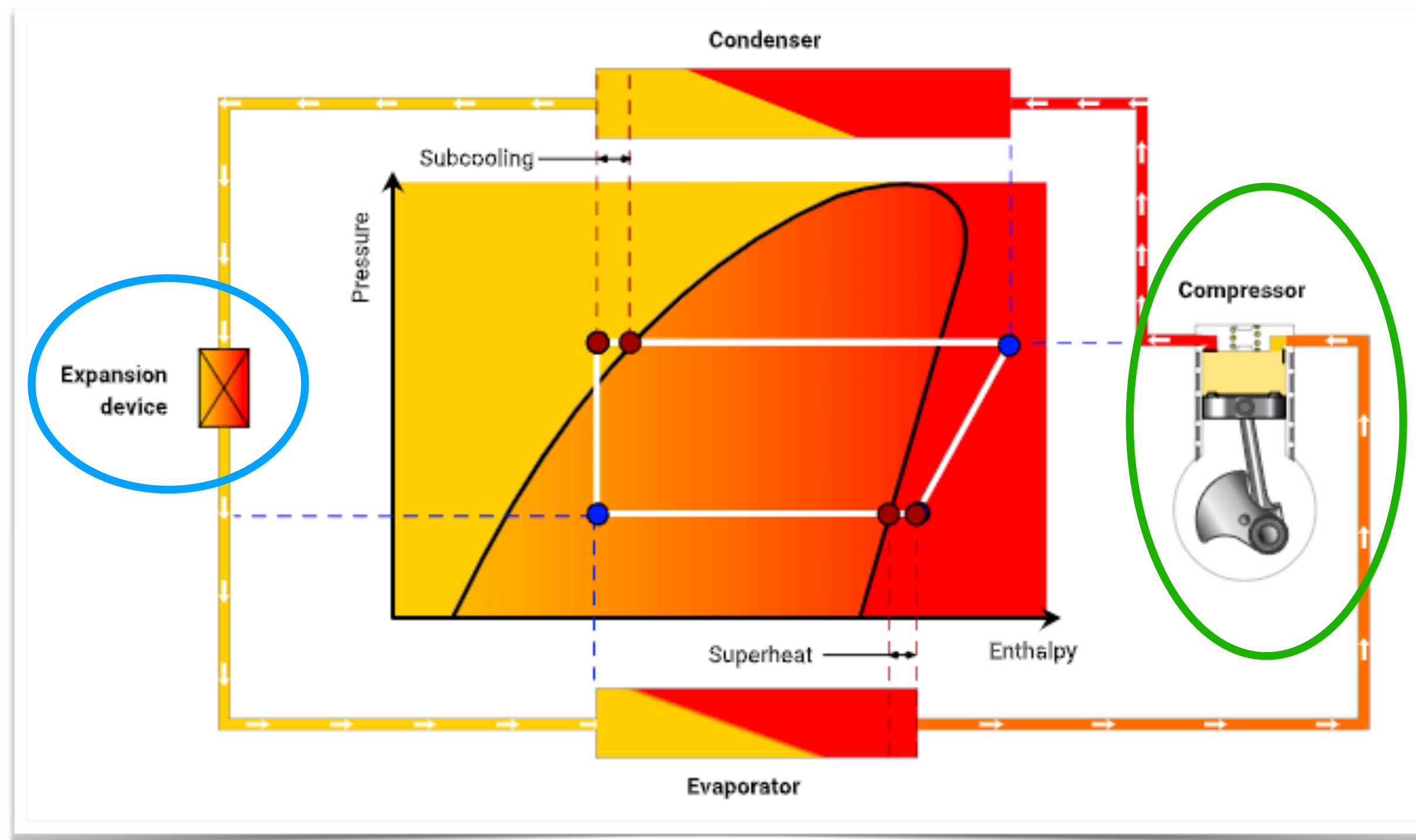- Expansion valve opening

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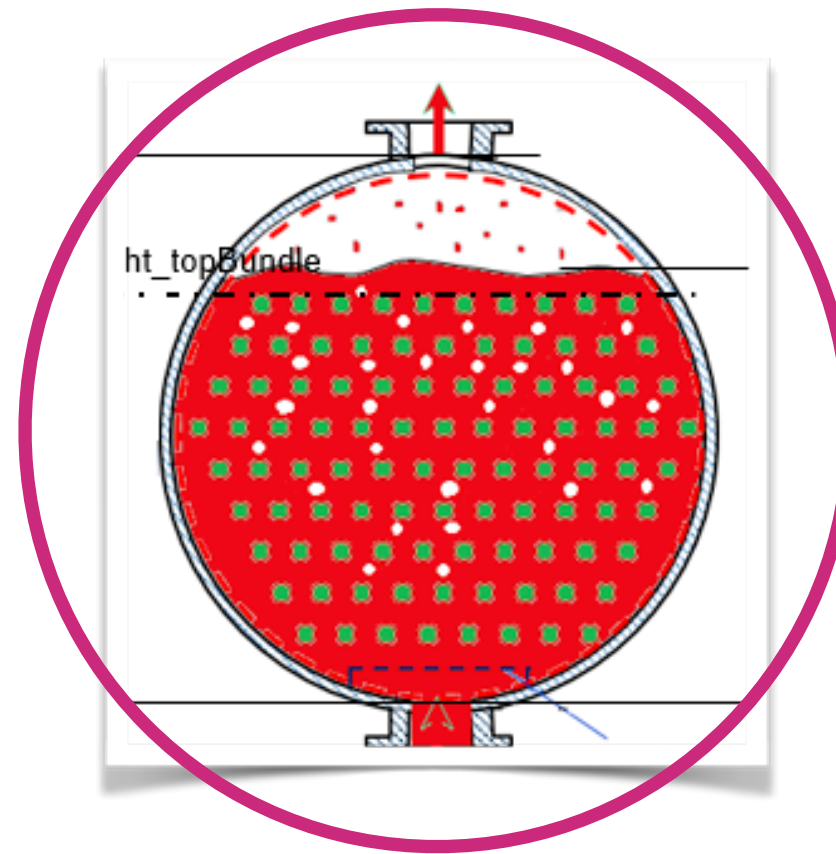
Objectives and constraints:
- **Achieve requested out-water temp**
- **Maximize efficiency** (COP)
  - Correlated to refrigerant level in evaporator
- Satisfy constraints such as
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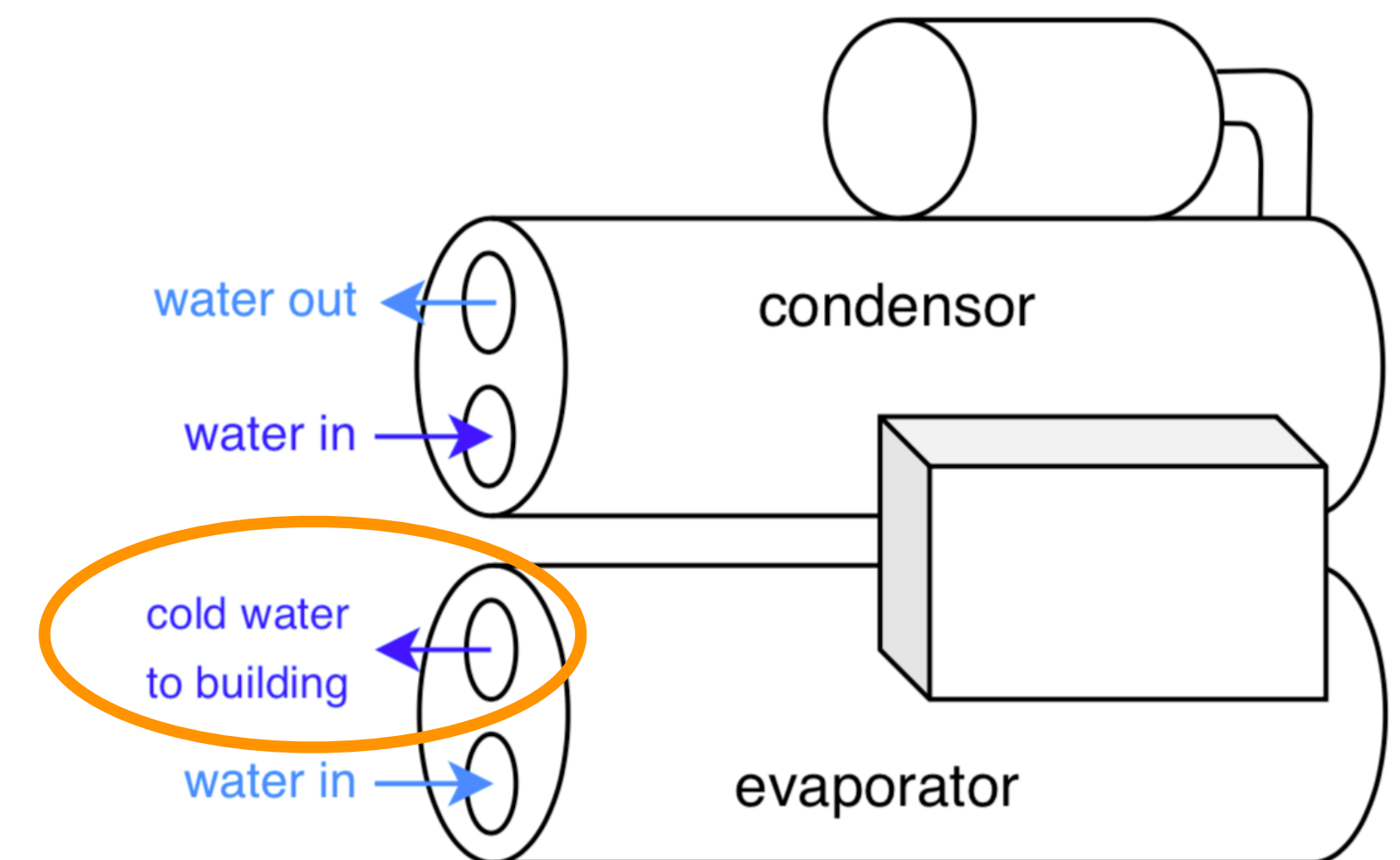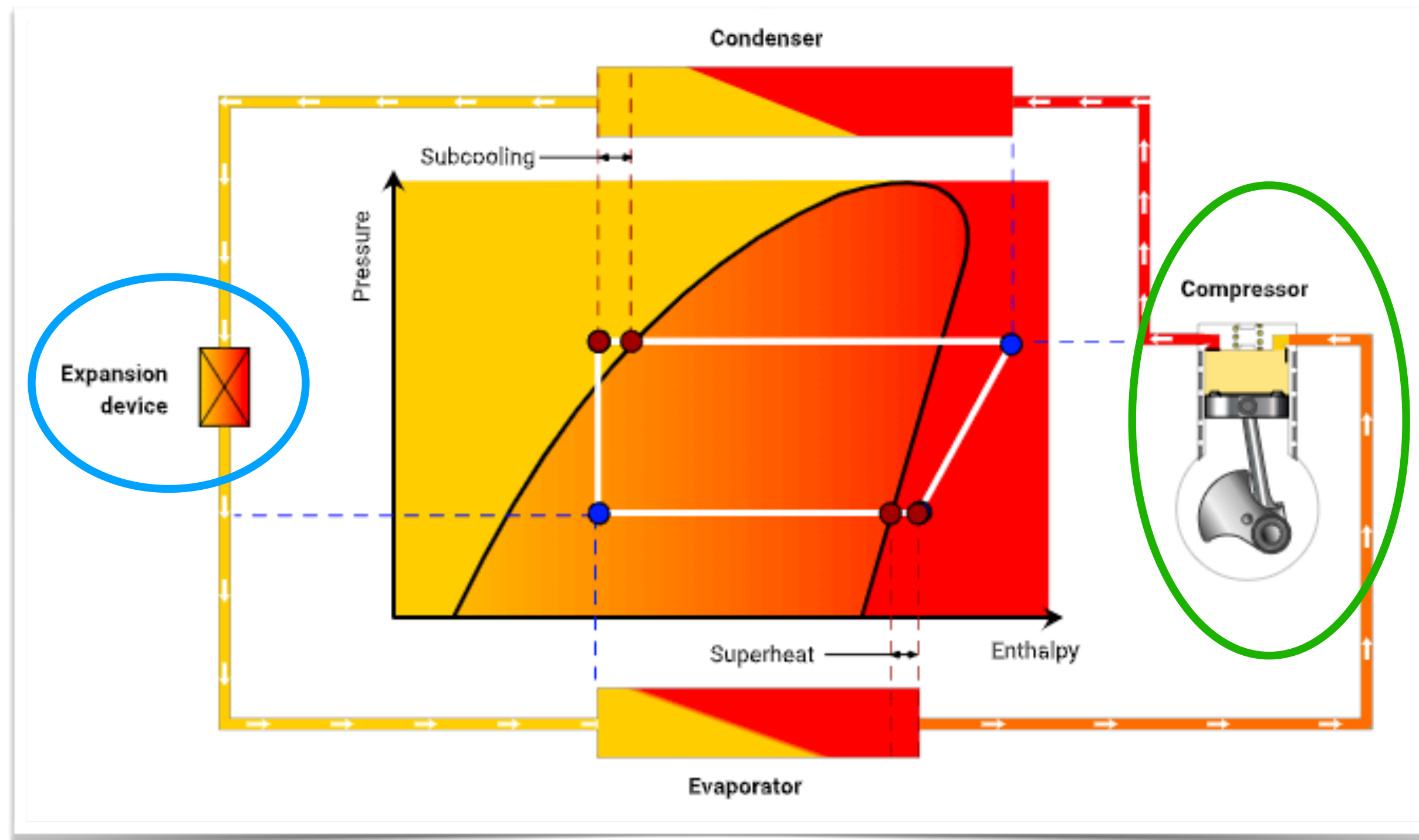 - Actuator limitations

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System outputs:
- Evaporator LWT
- Evaporator level

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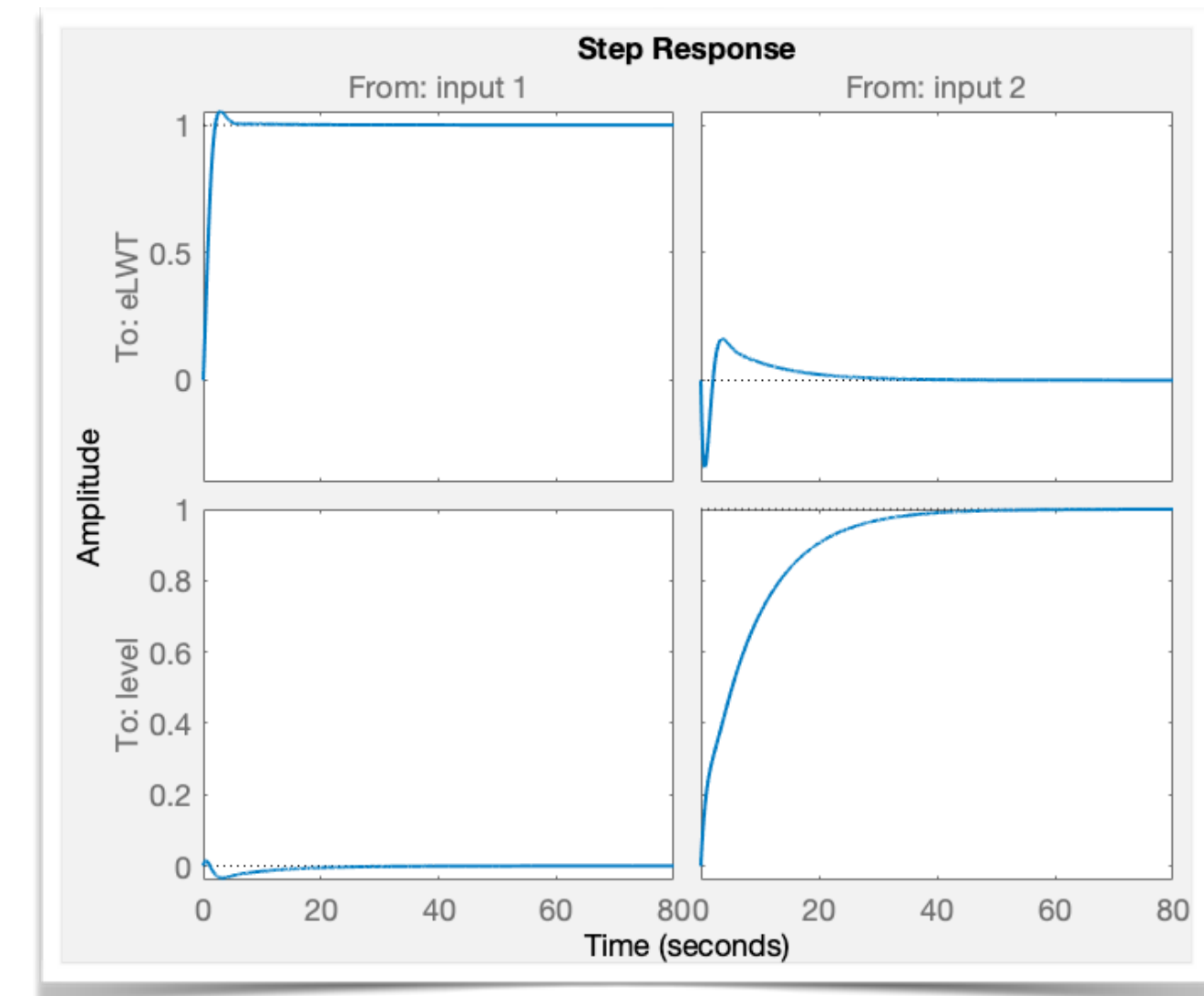- Compressor speed
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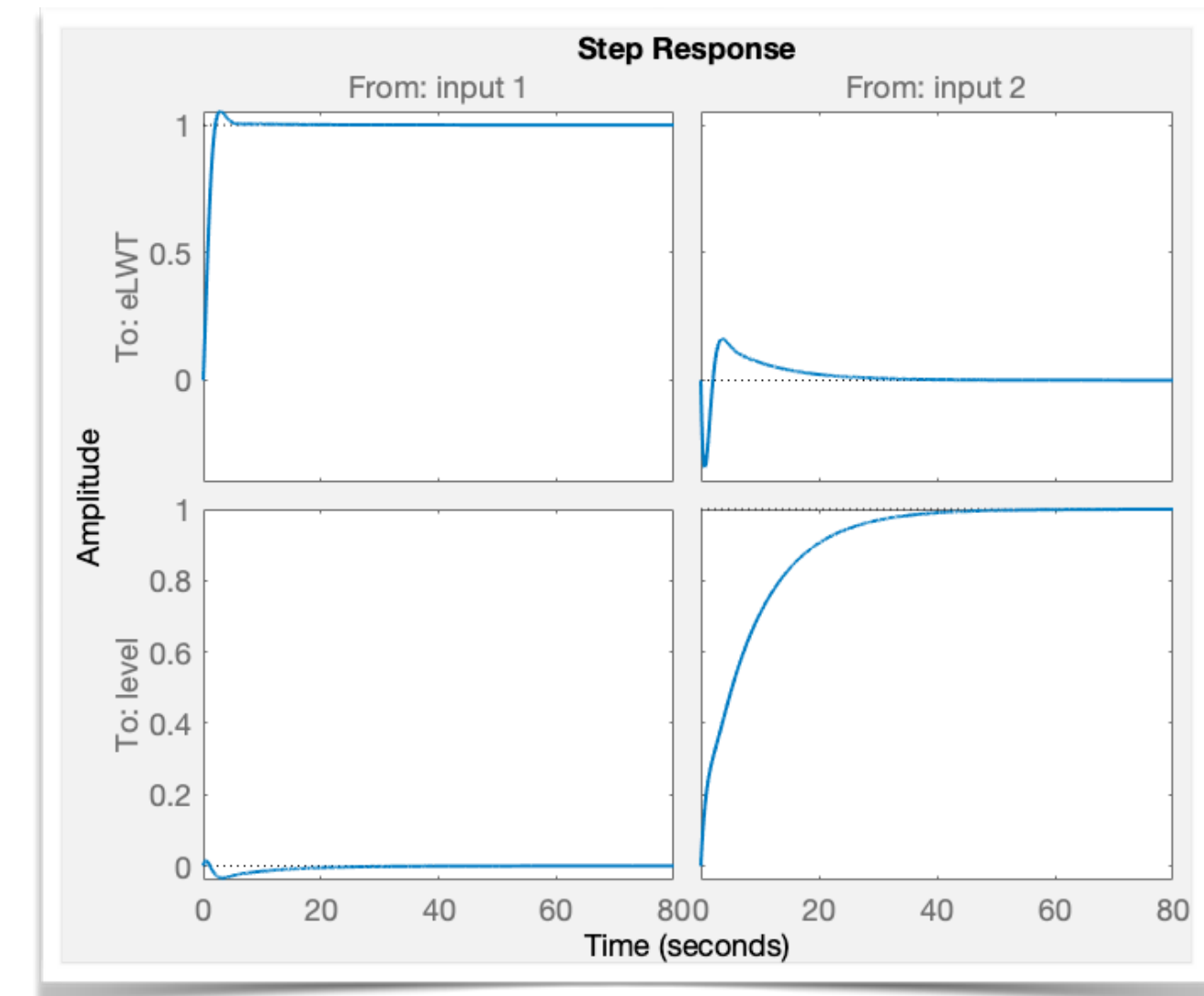- Evaporator level

Controller structure:

$$C(s) = G^{-1}(0) \begin{bmatrix} C_1(s) & 0 \\ 0 & C_2(s) \end{bmatrix}$$

with PI-controllers $C_1(s)$ and $C_2(s)$,
where $G(s)$ is a linearization of the system

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Chosen PI-controllers:

$$C_1(s) = 0.1 \left(1 + \frac{1}{s} \right), \quad C_2(s) = 1 \left(1 + \frac{1}{5s} \right)$$

Step Response

Controller

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- Compressor speed
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System outputs:
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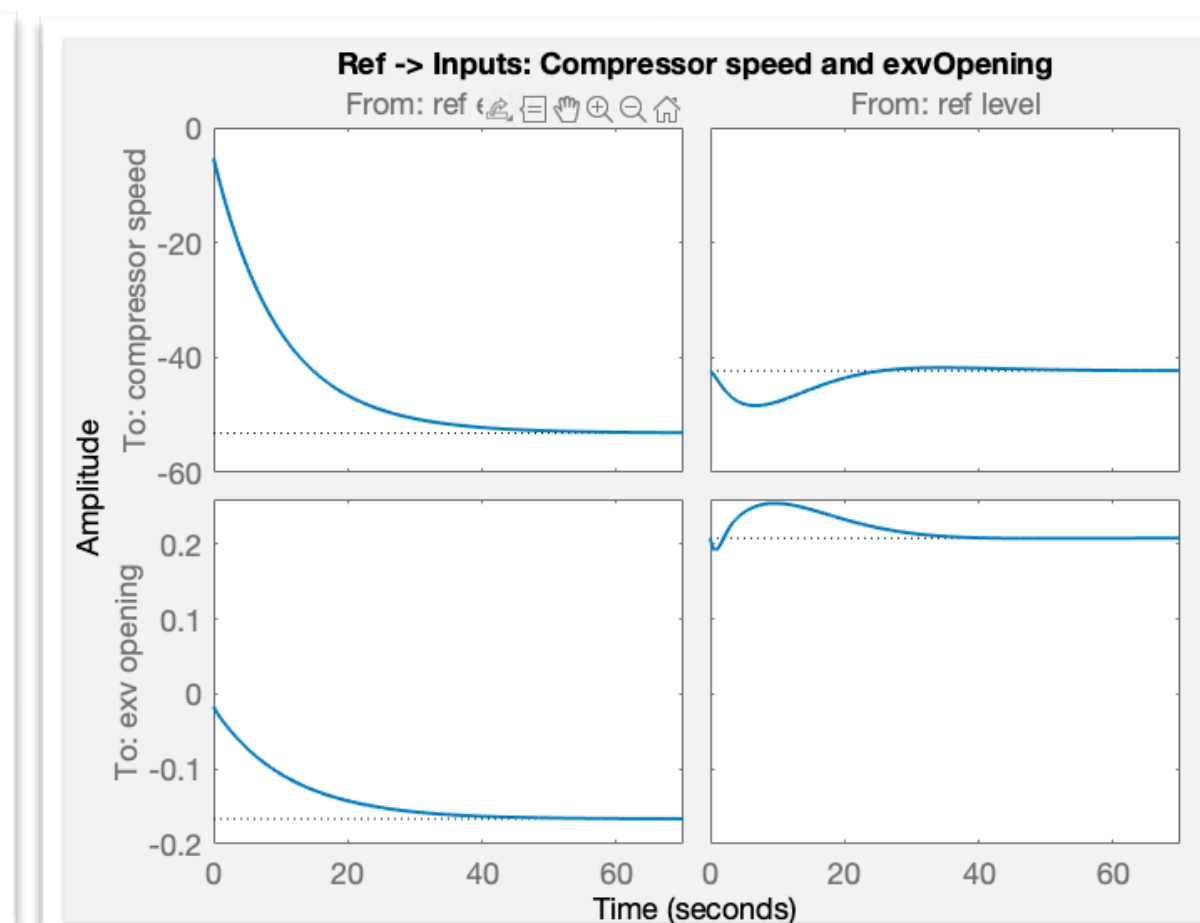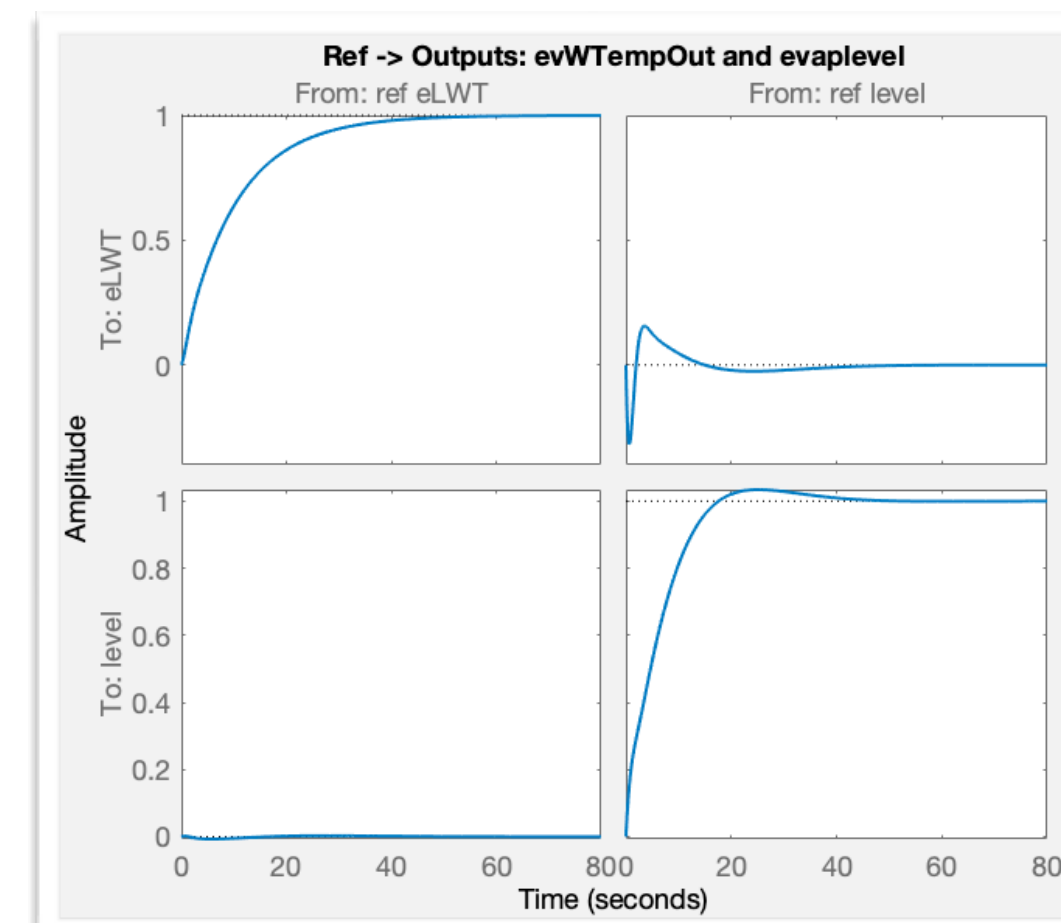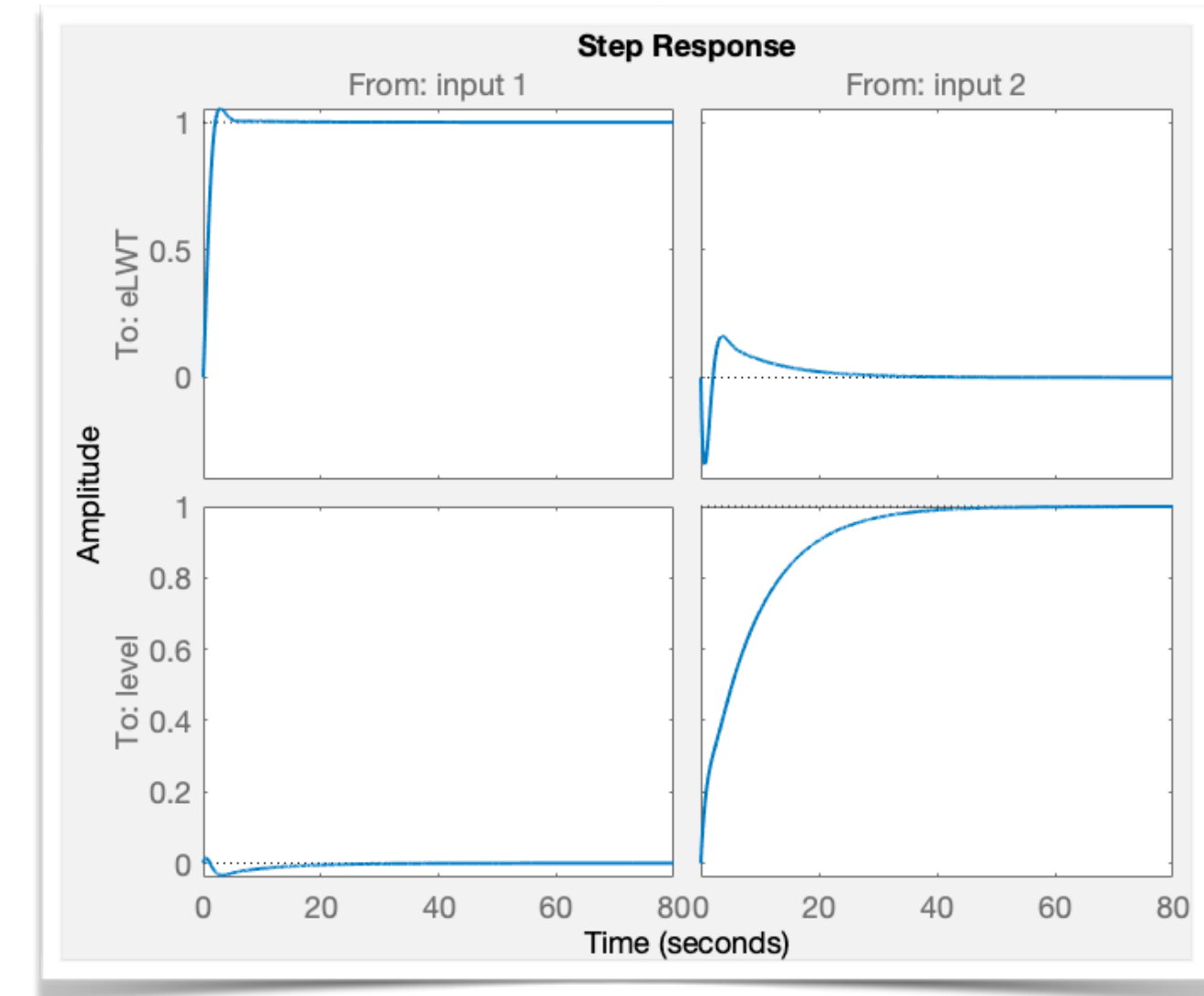
Controller tests

Controller performance for reference changes (eLWT and evap level) **and disturbances**

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- cond entering water temp (cEWT)

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cold water to building ←

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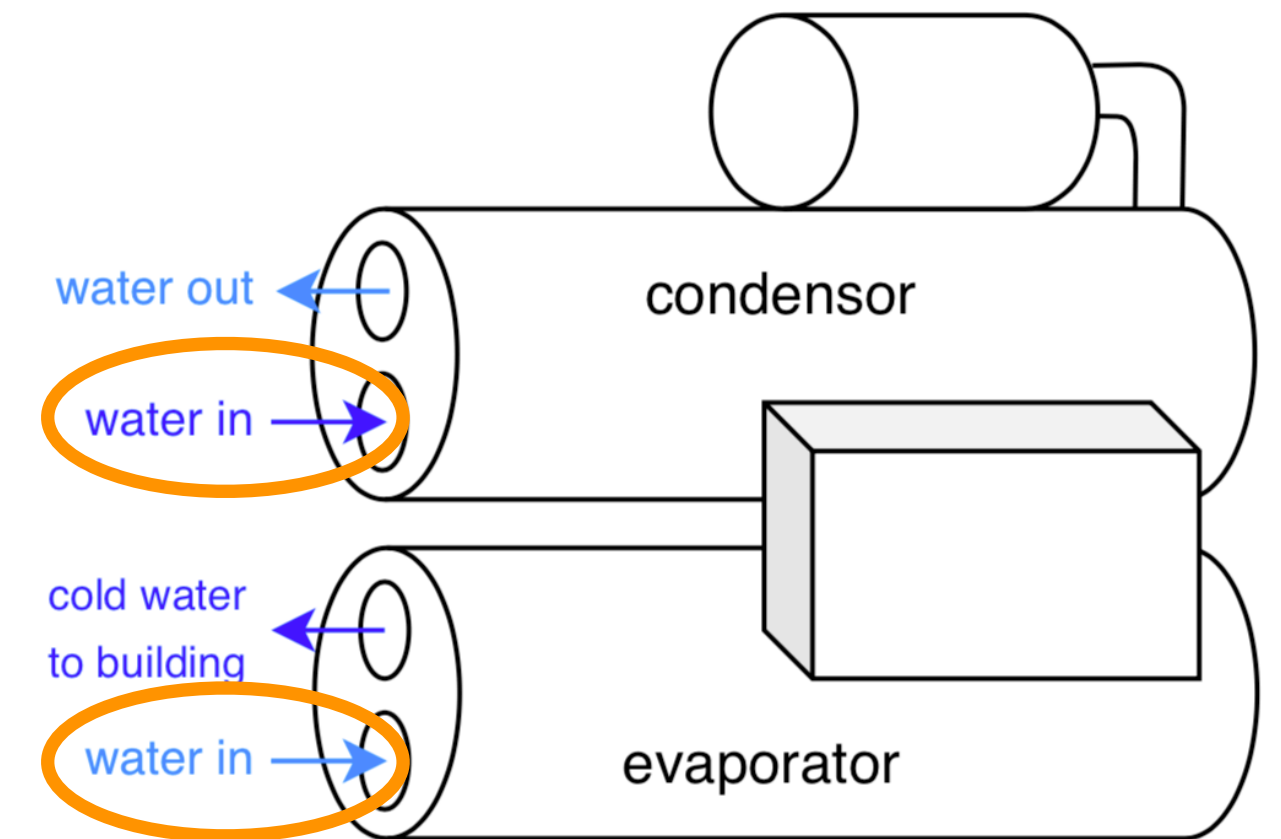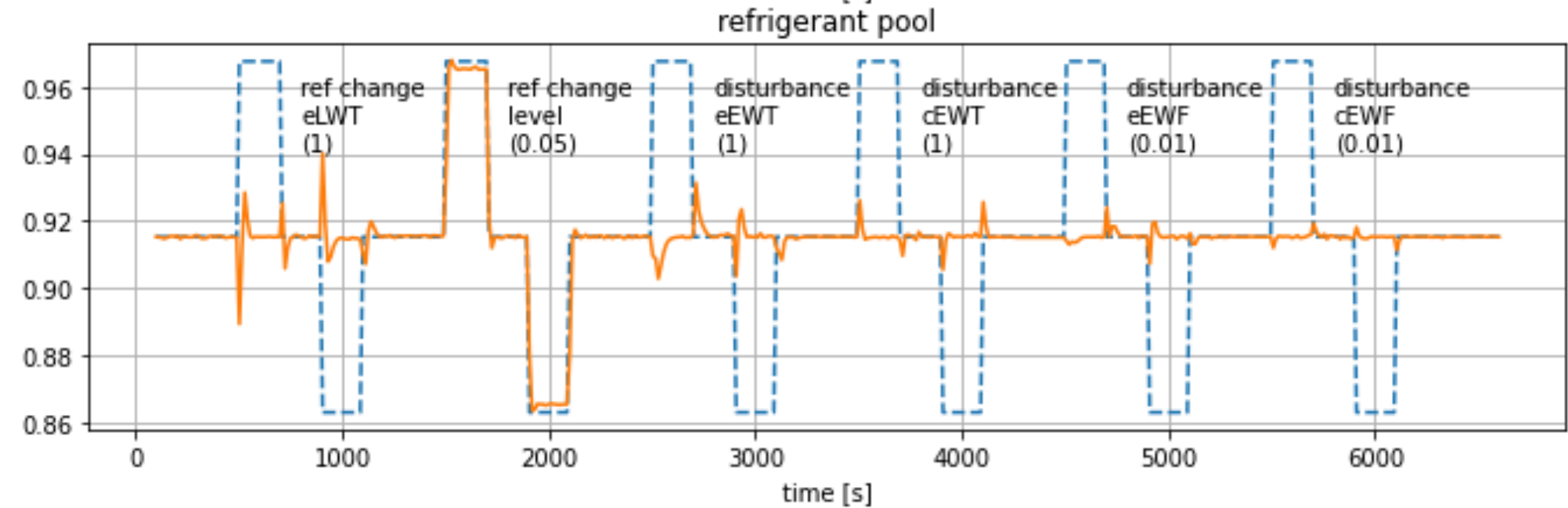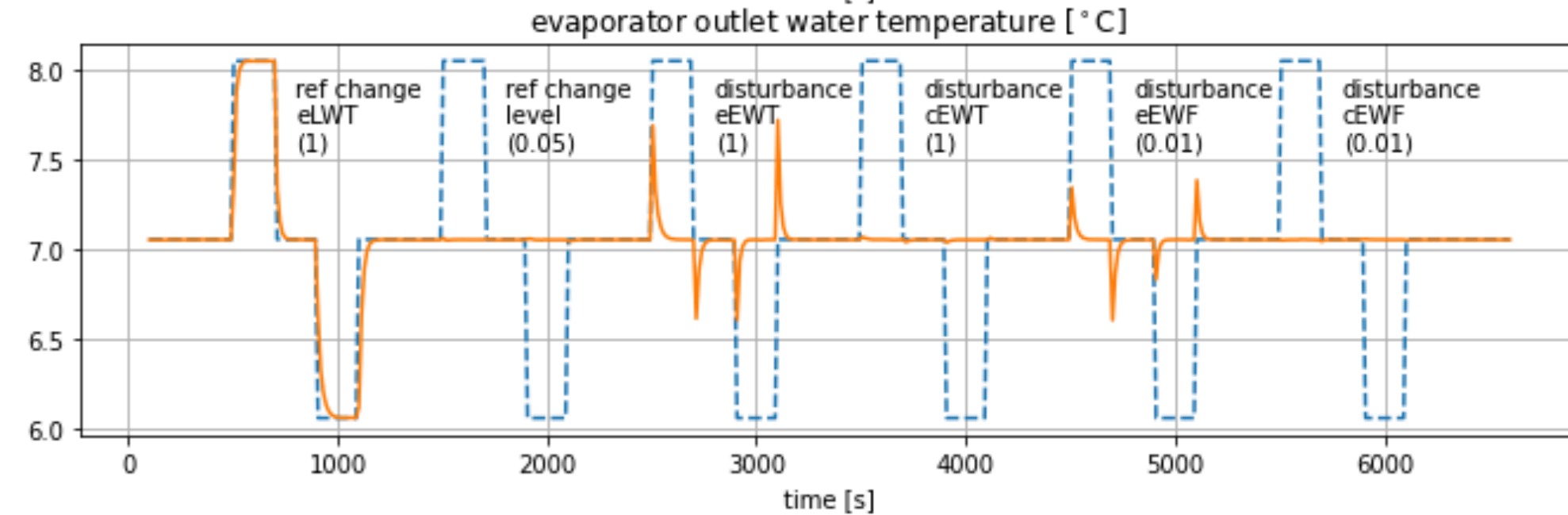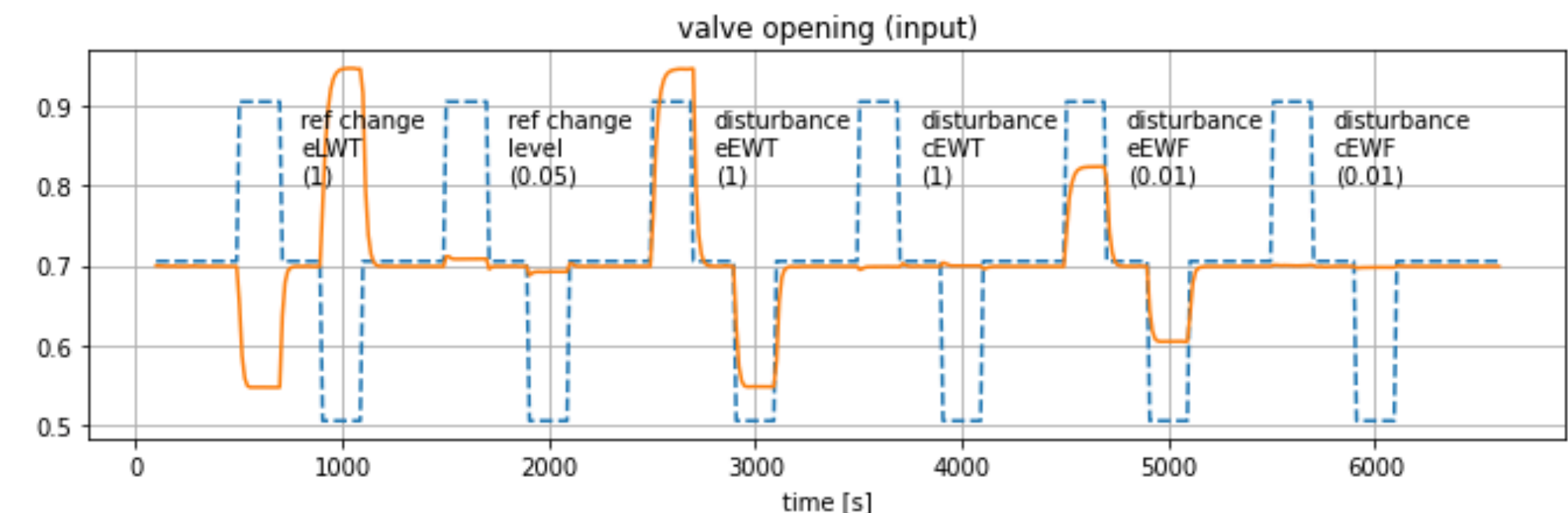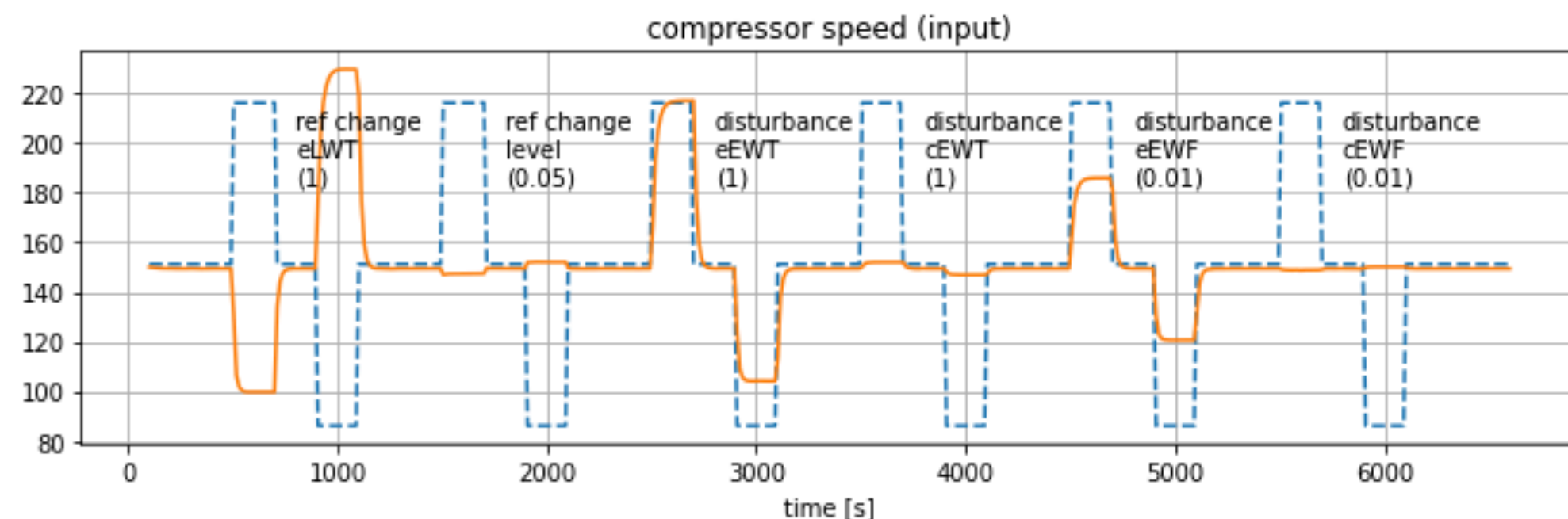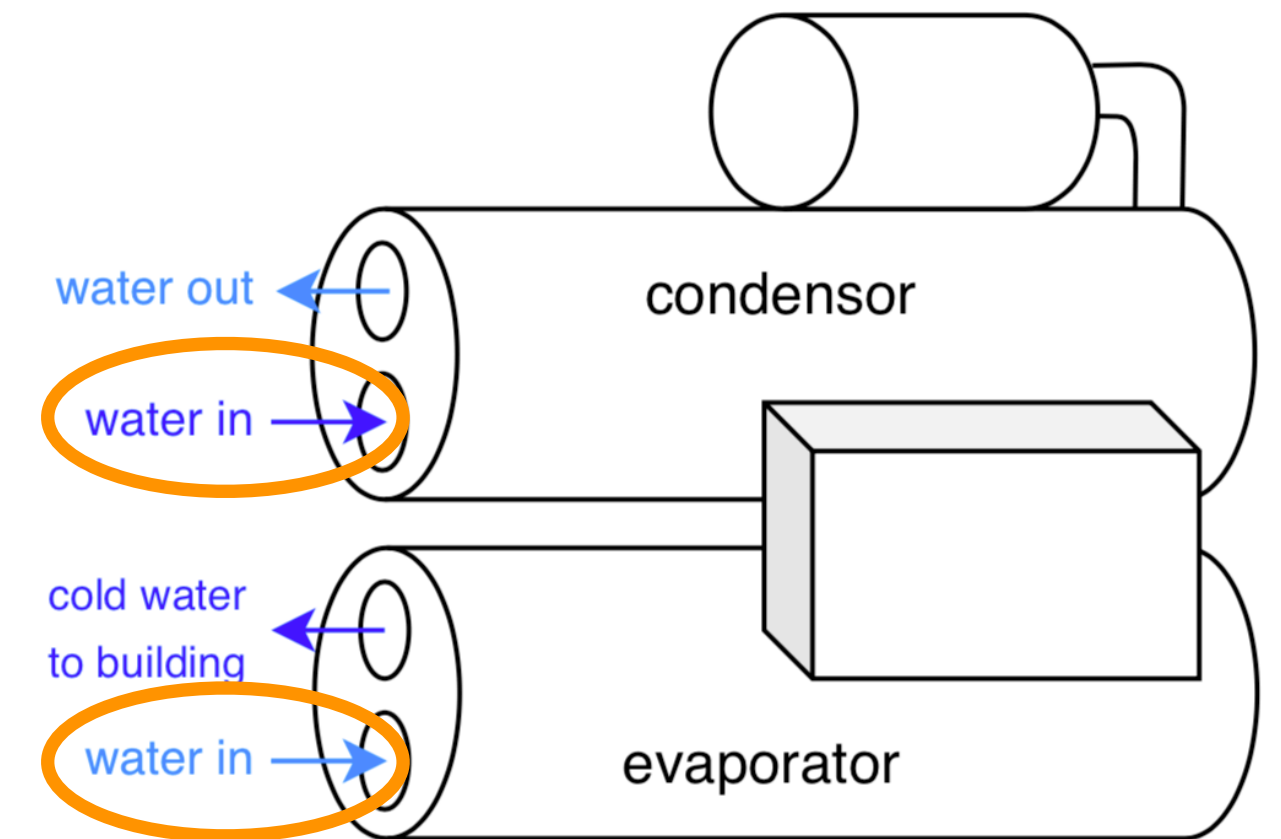
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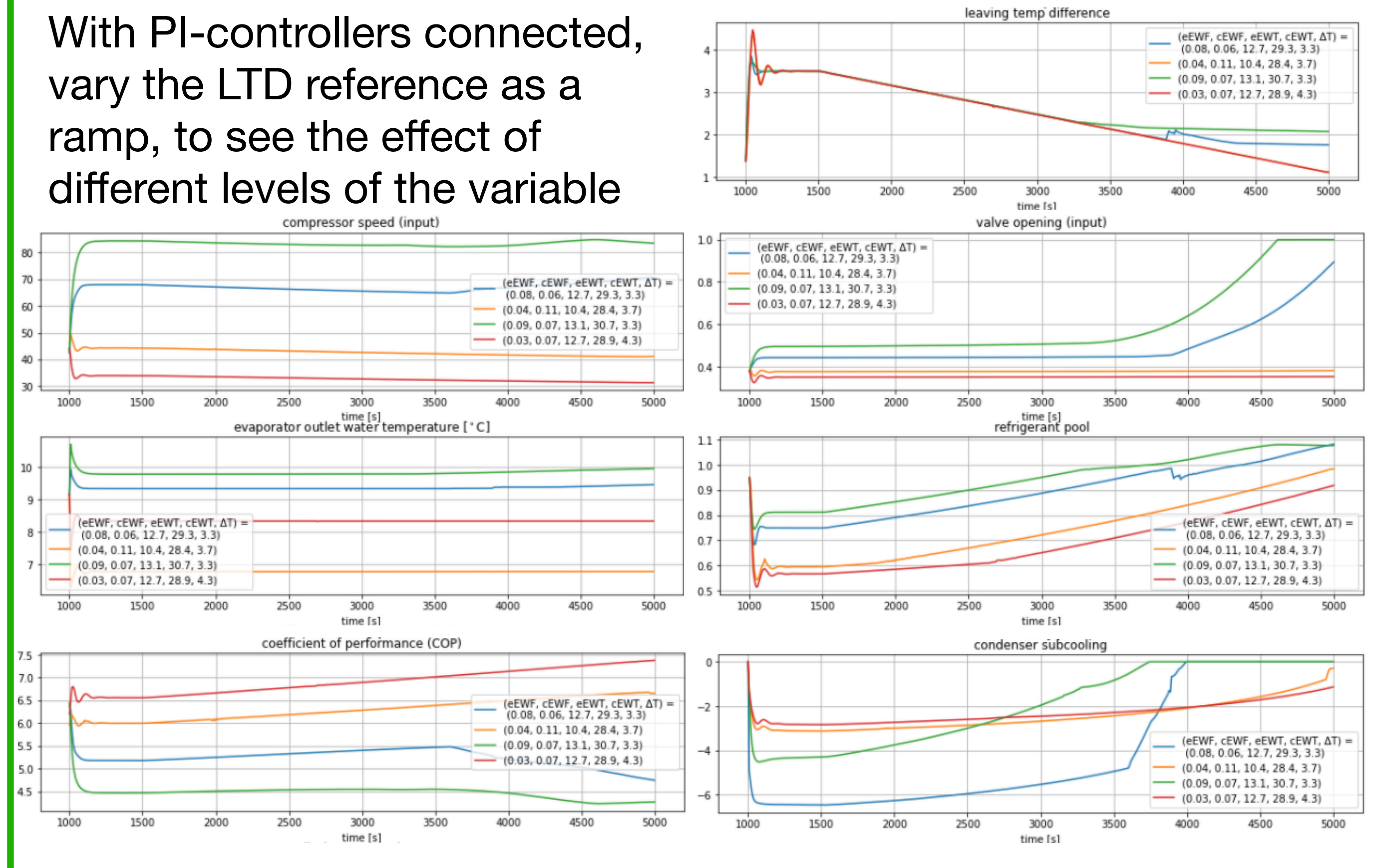**Problem:** The evaporator level is not measurable

Possible solutions:
1. Add an expensive sensor
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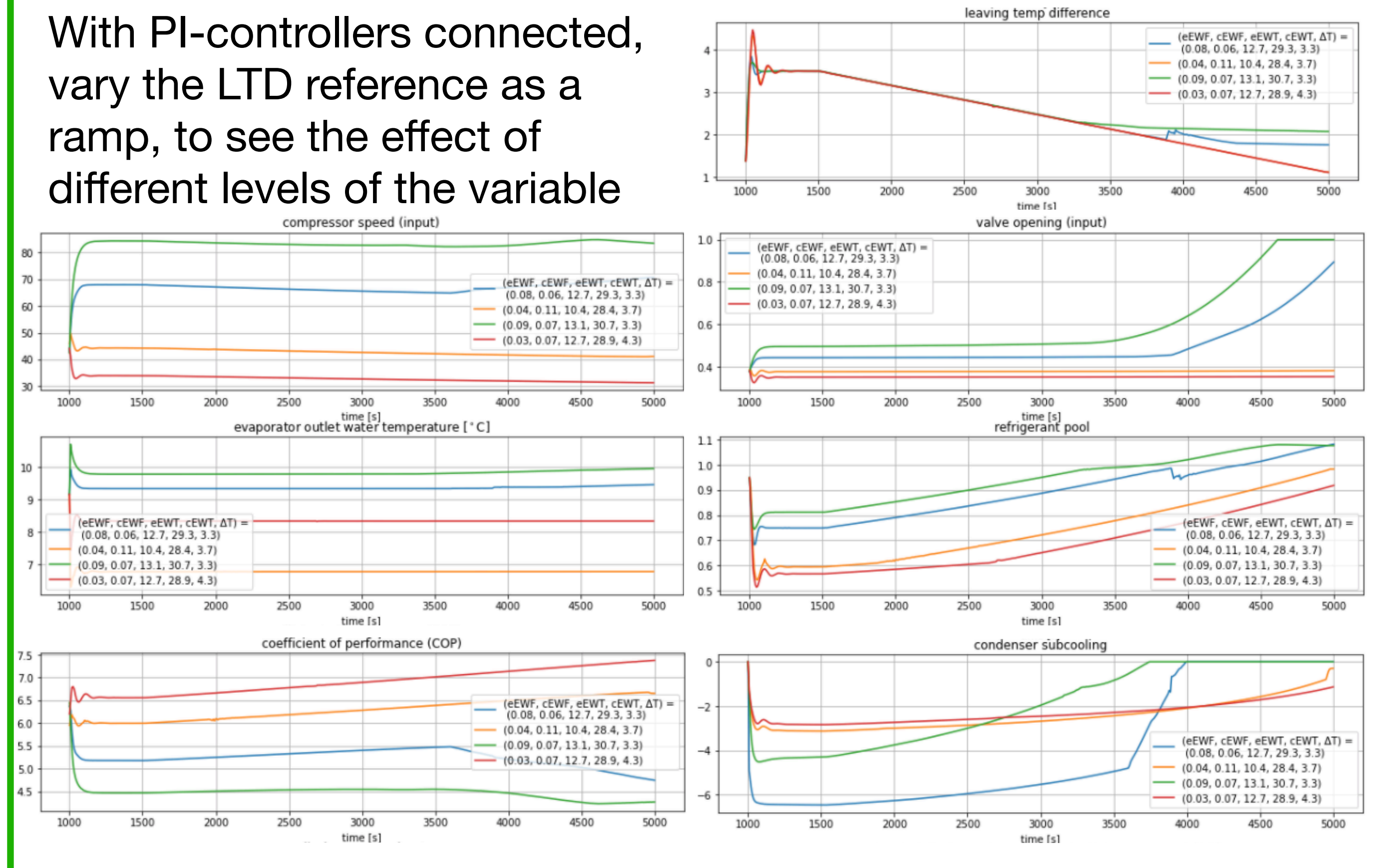**Problem:** The evaporator level is not measurable

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Idea: Use learning methods to find an LTD reference level that keeps the subcooling away from zero, the evaporator level <1, and high COP, for given operating conditions.

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- Support Vector Machines

- SVM (with and without kernels)

- Gaussian Processes

- Other methods?

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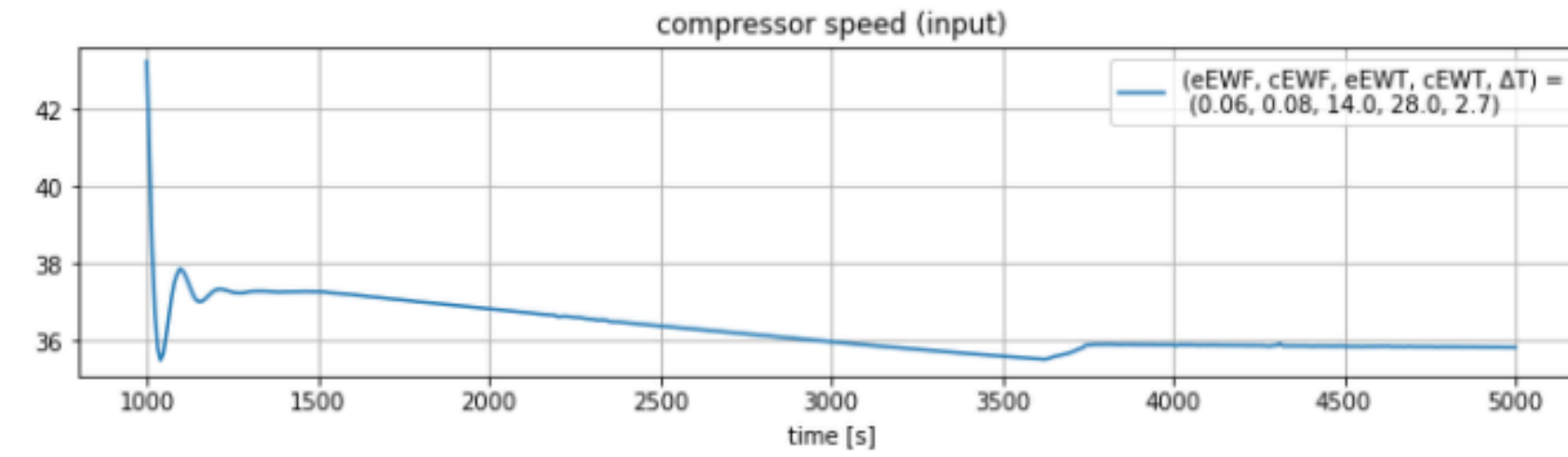
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Questions

- How to best generate training data?

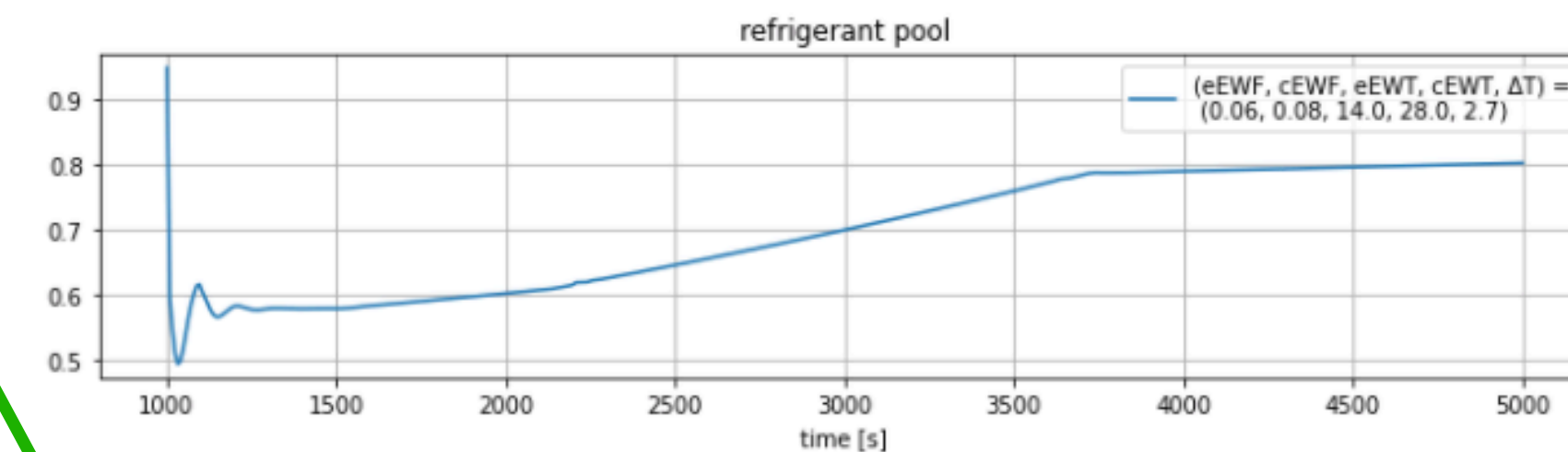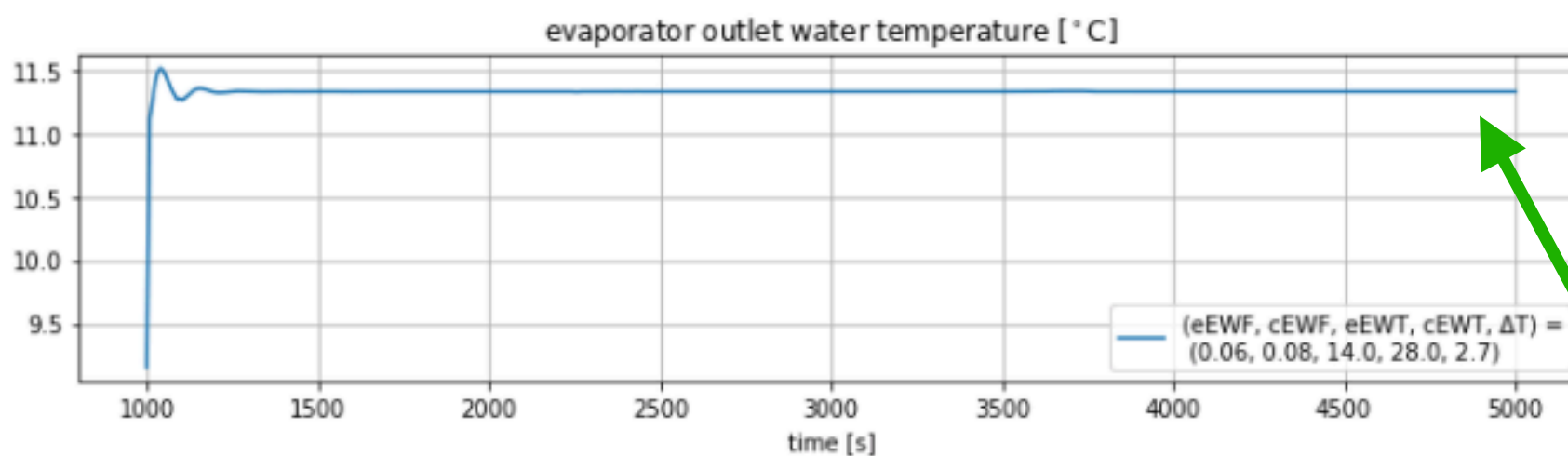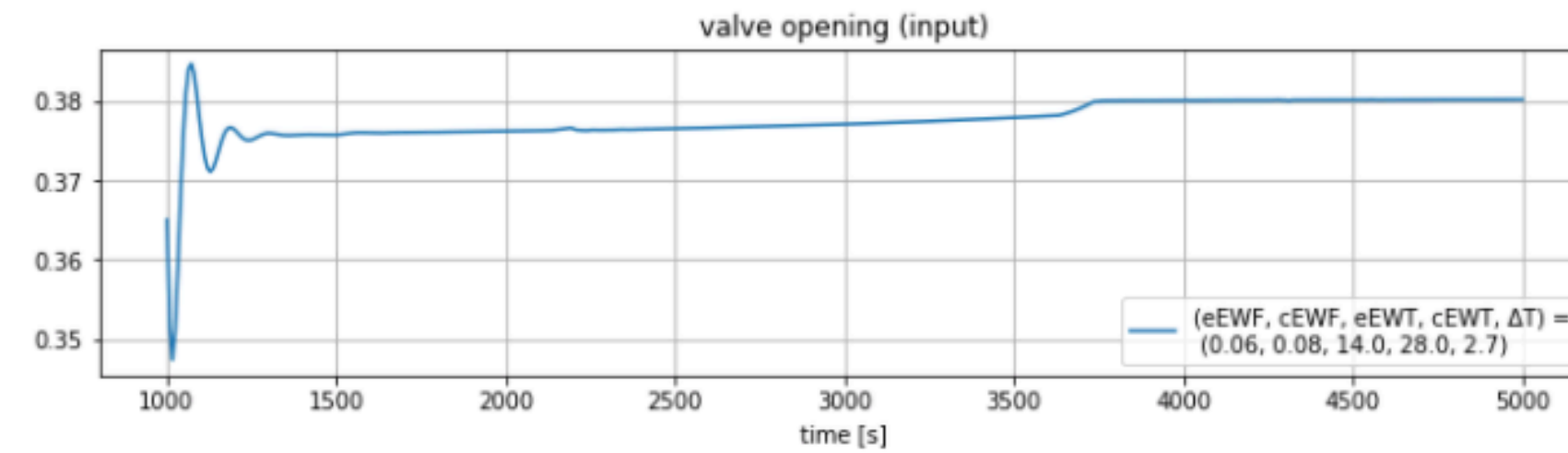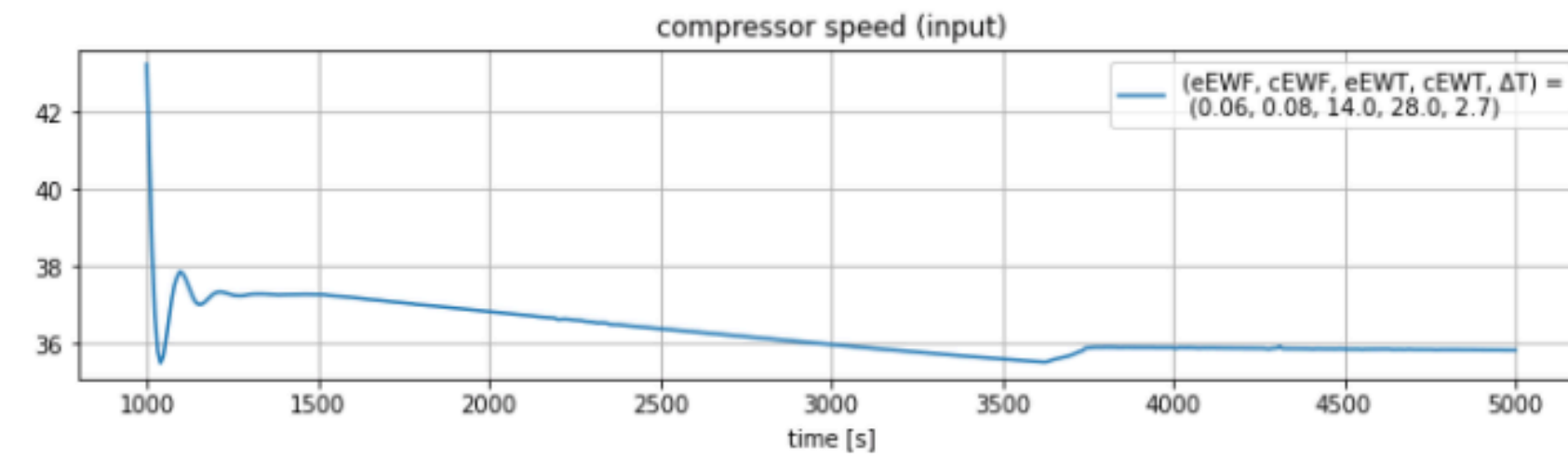- Which signals are most important?

Results from control with LTD
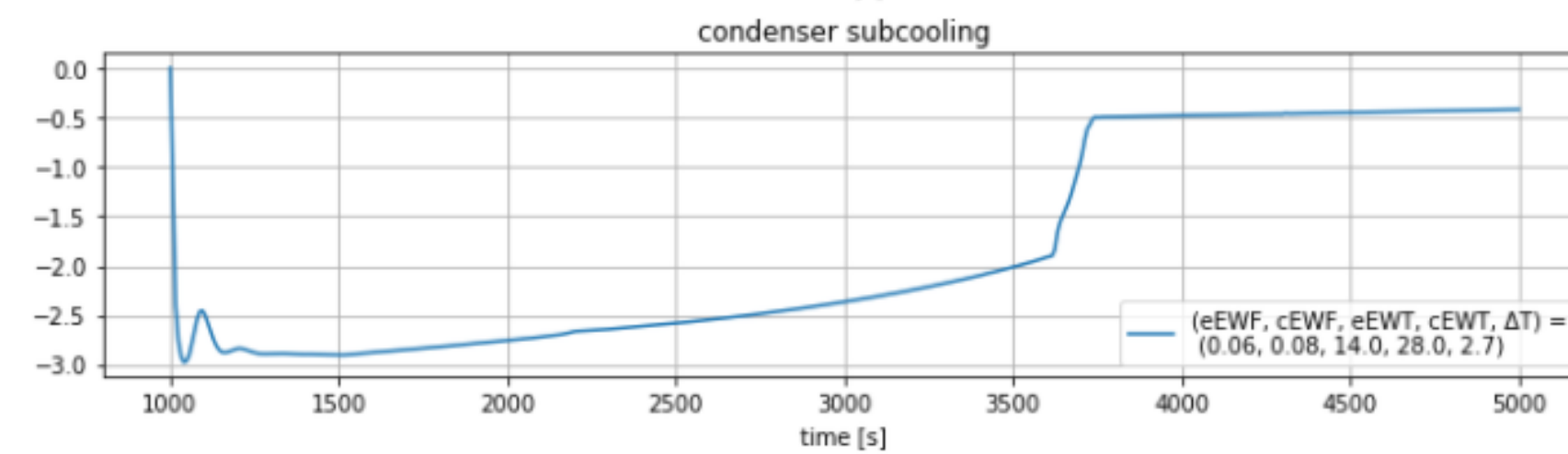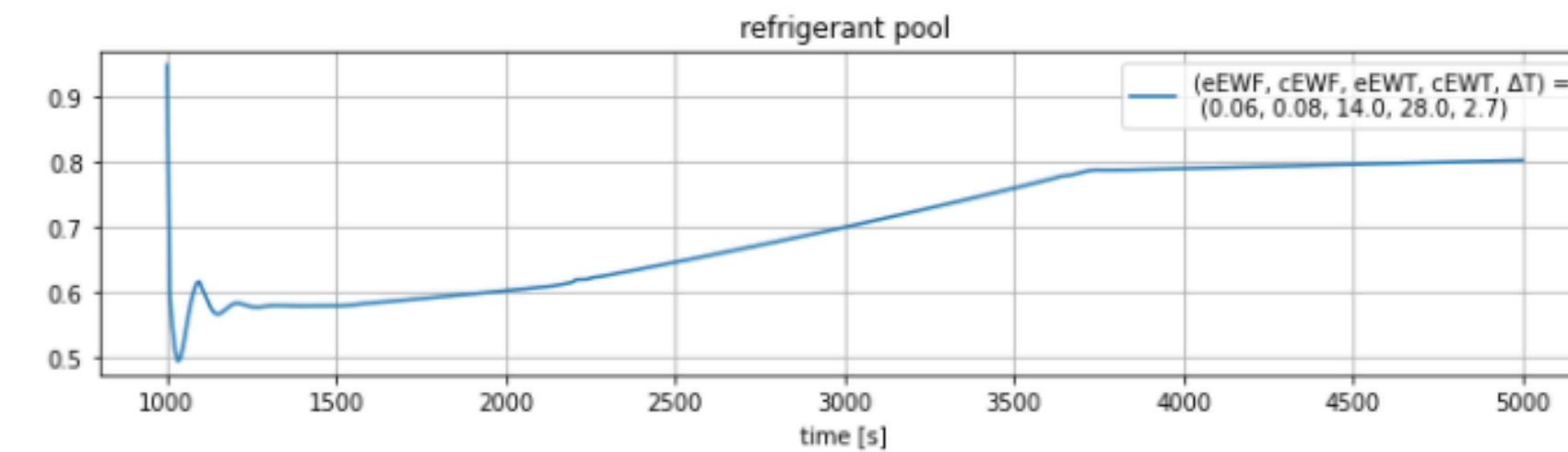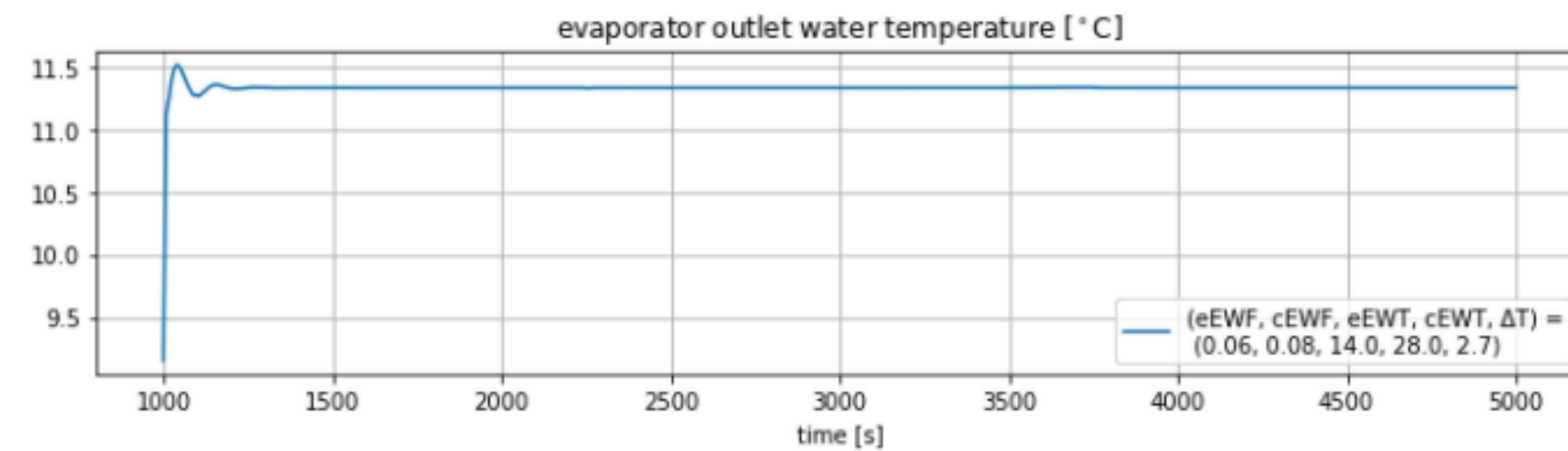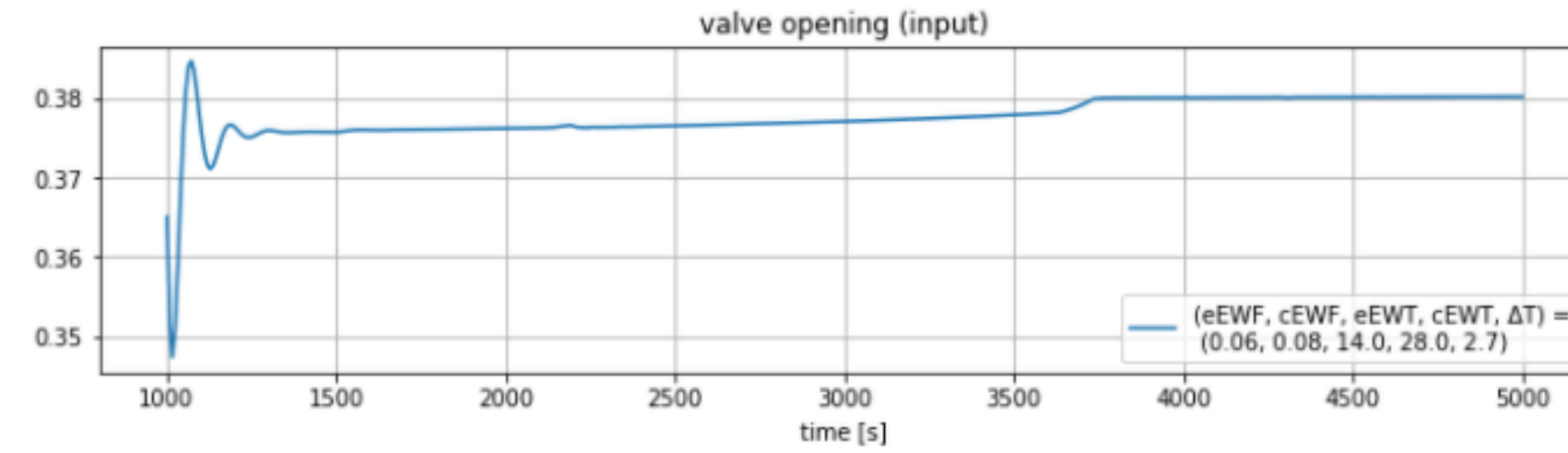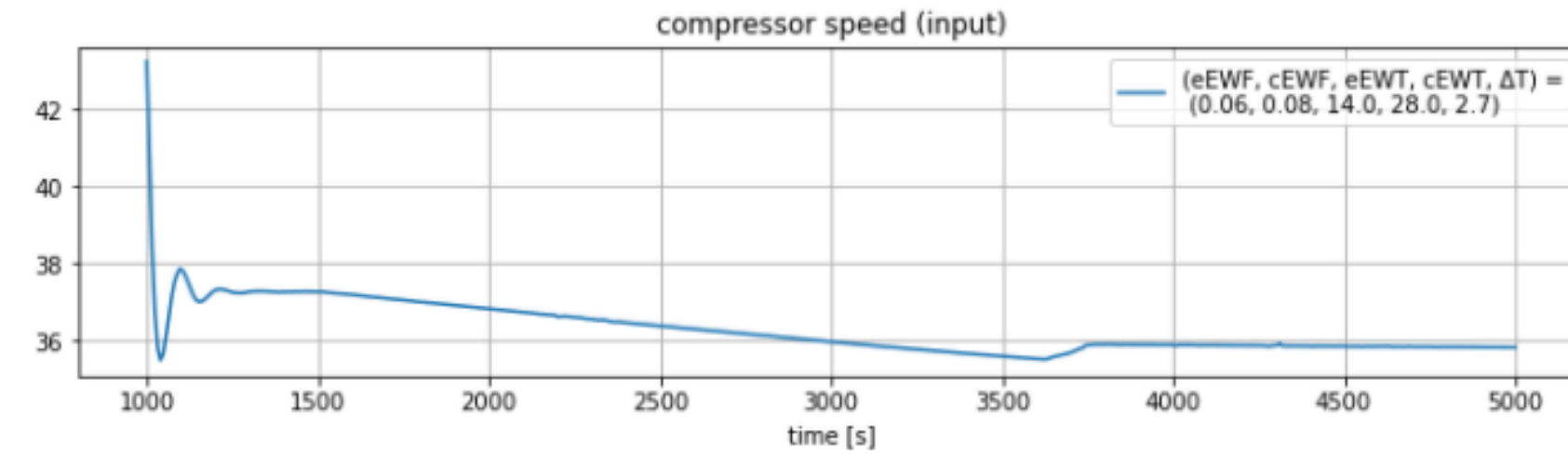
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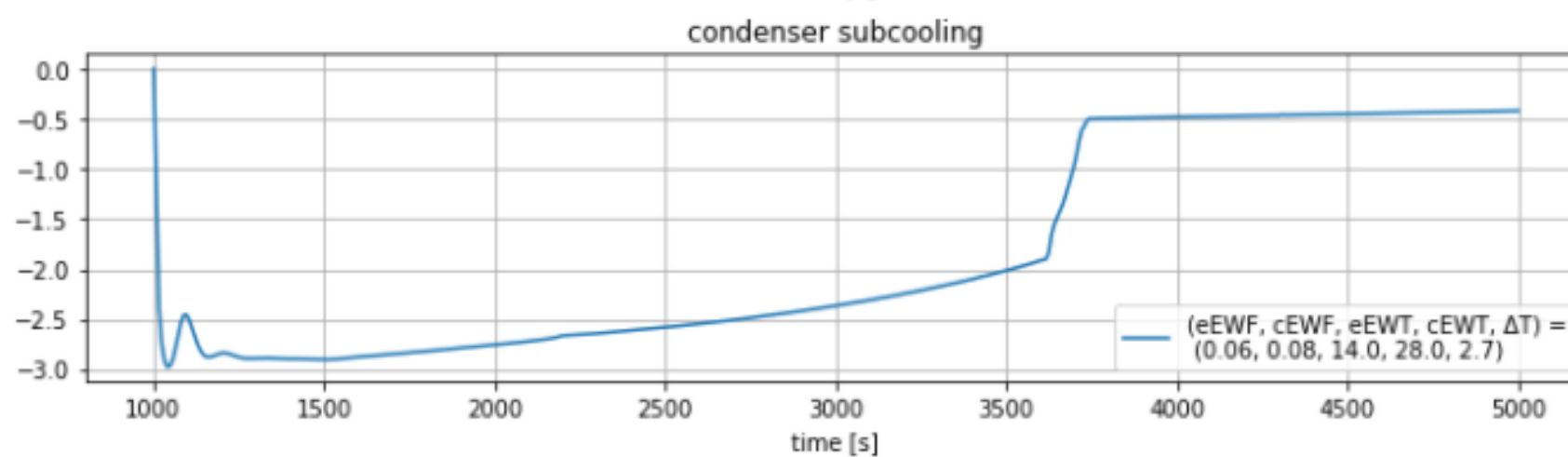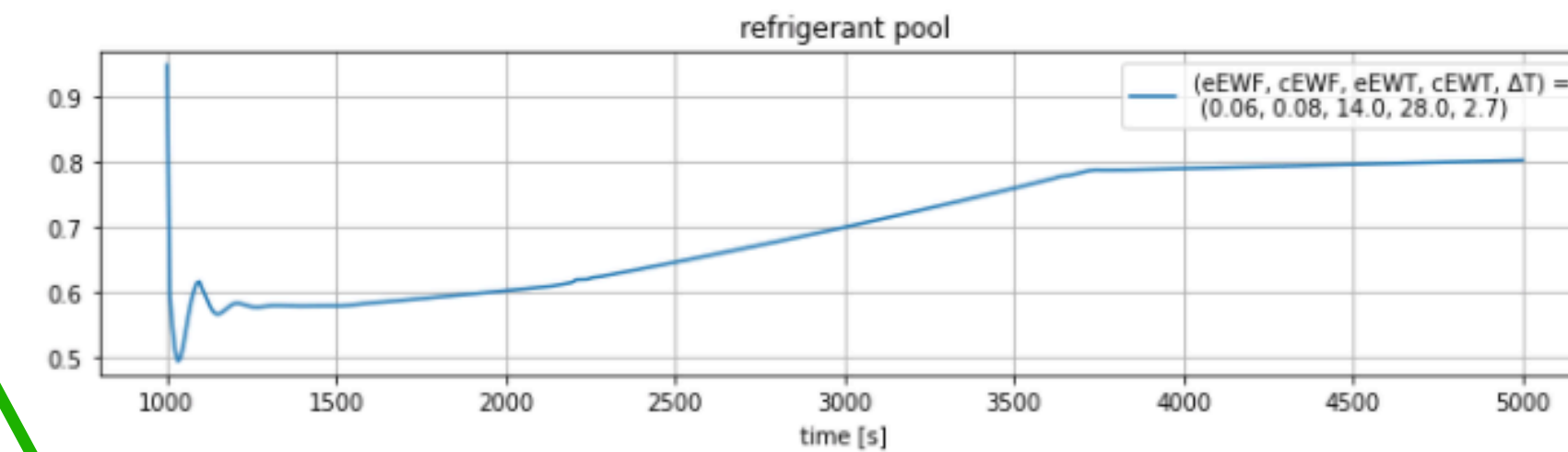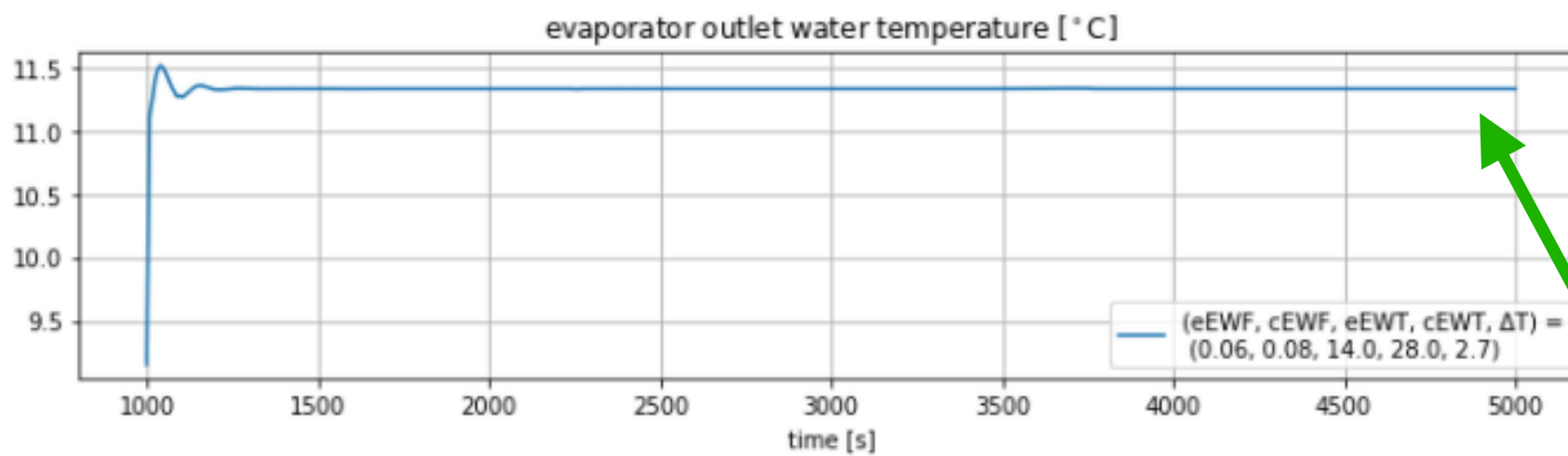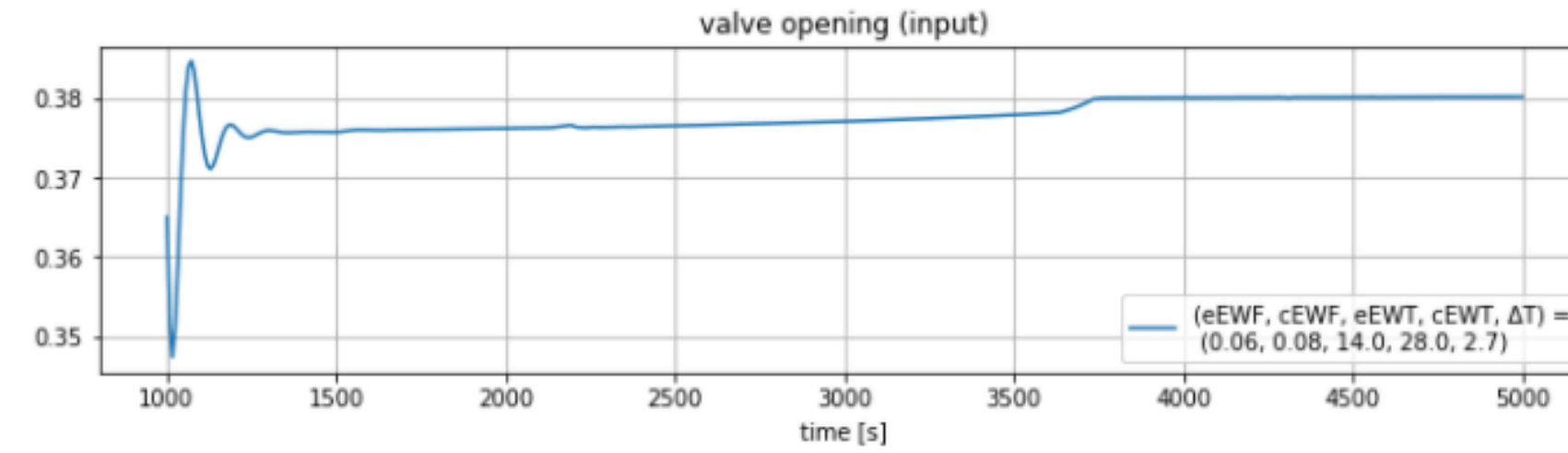
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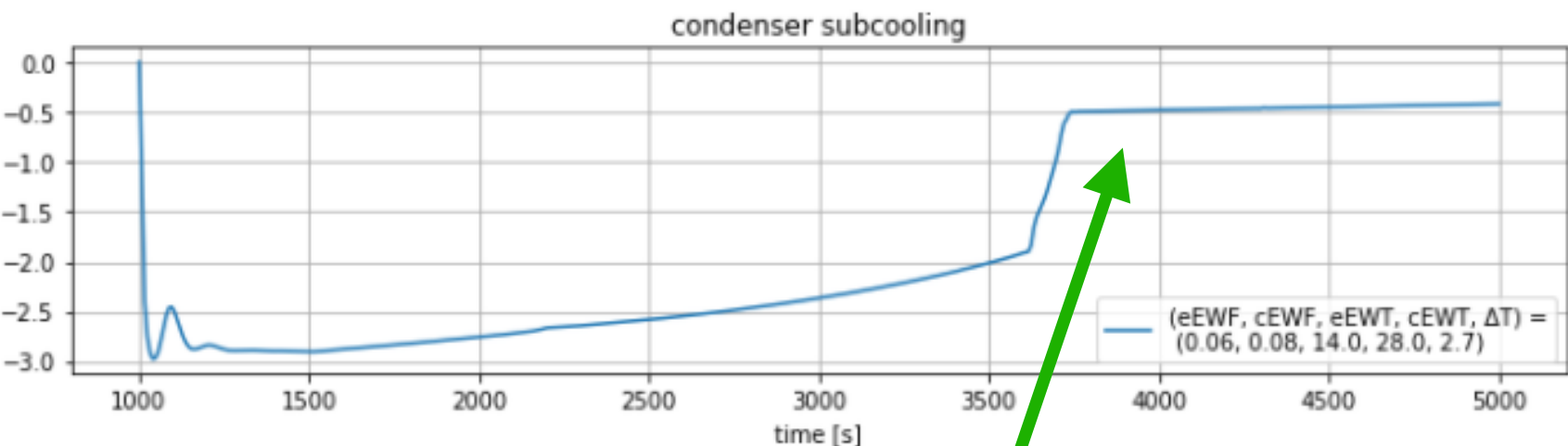
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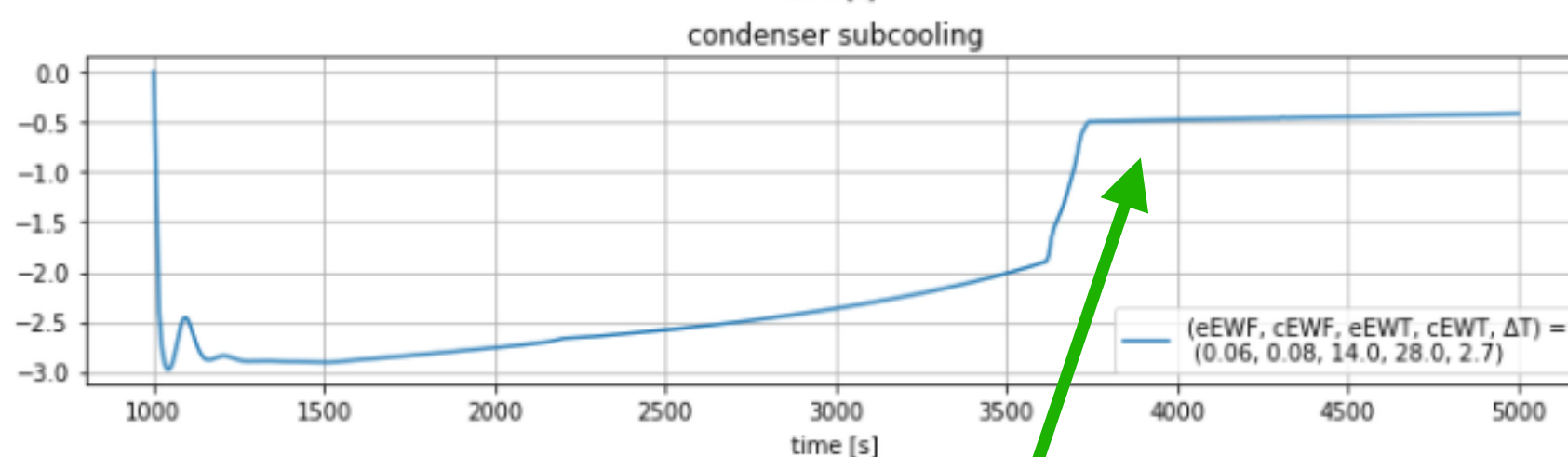
Reaches reference
temp of 11.3°C
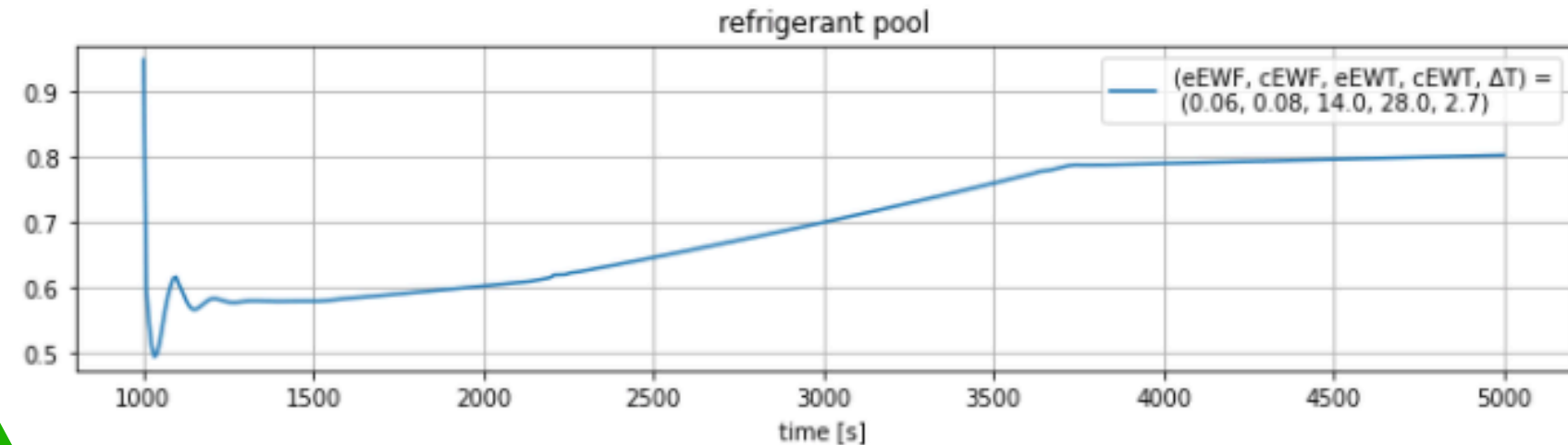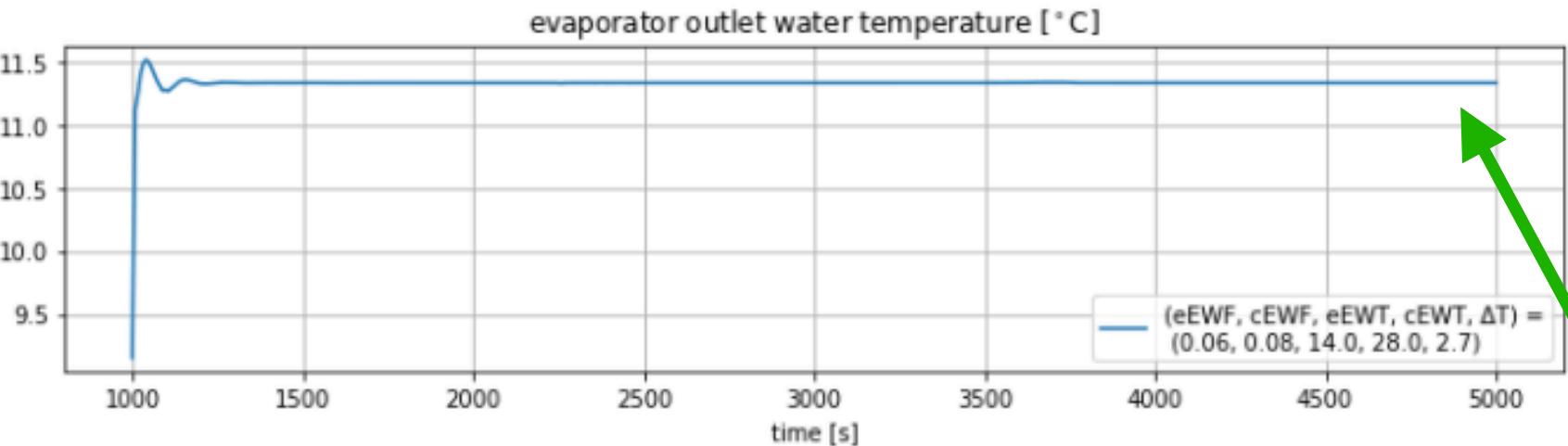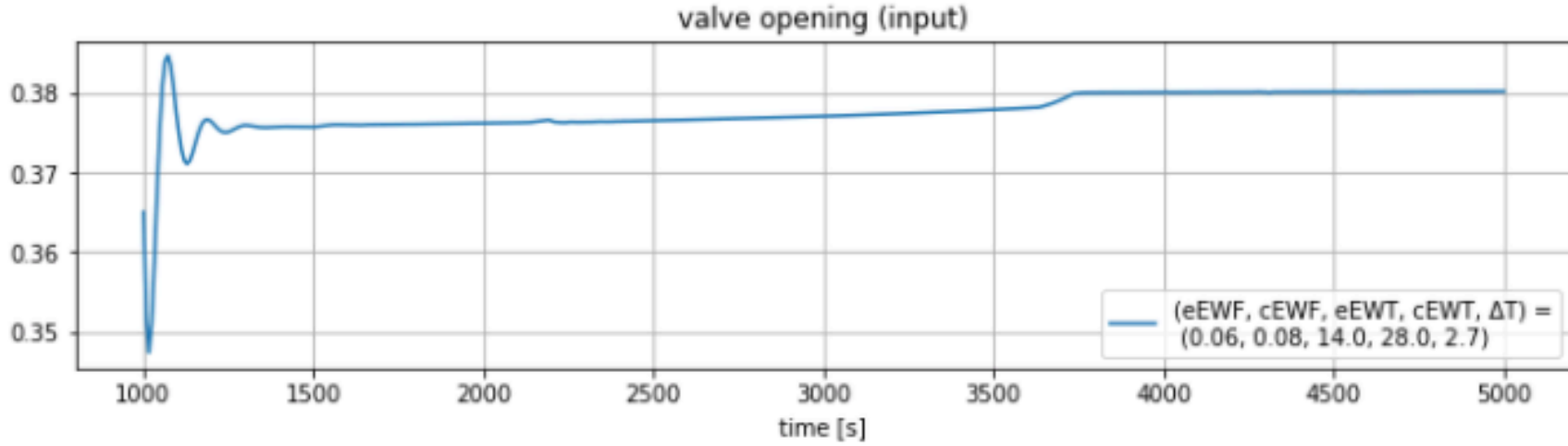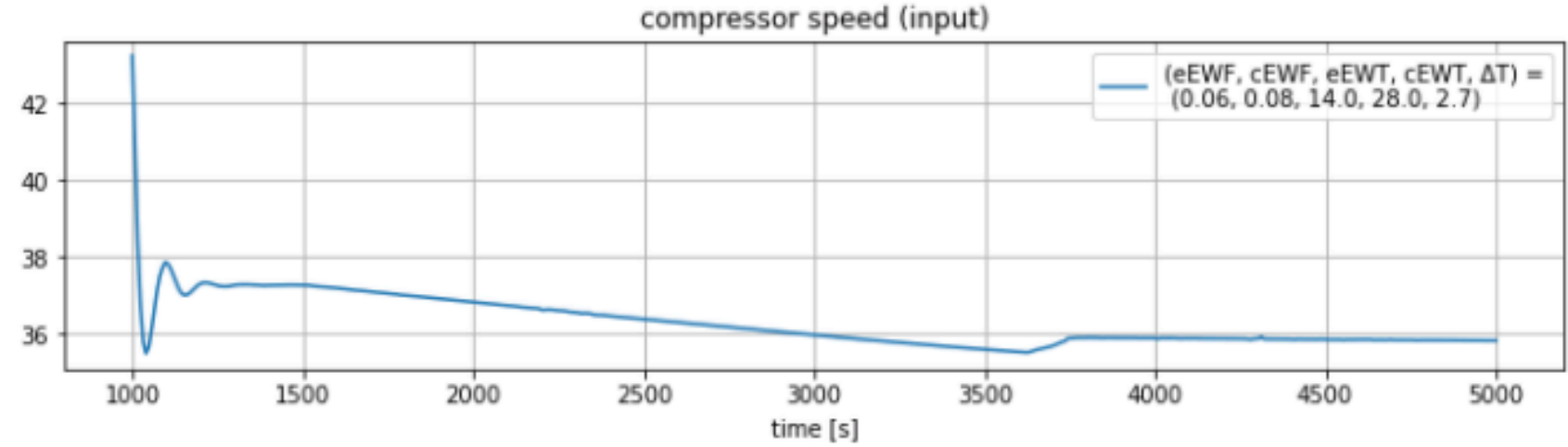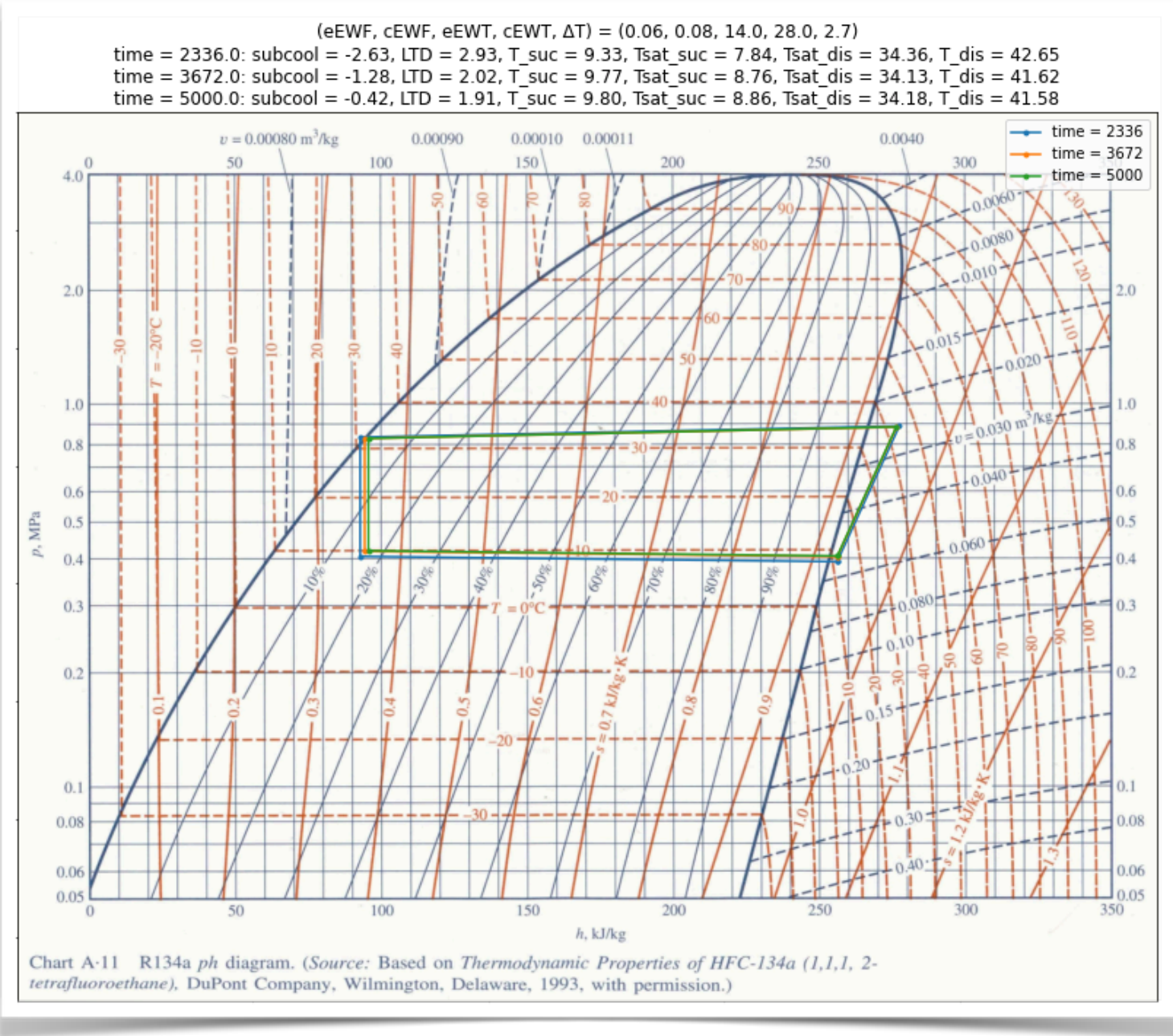
Feedback term added to counteract
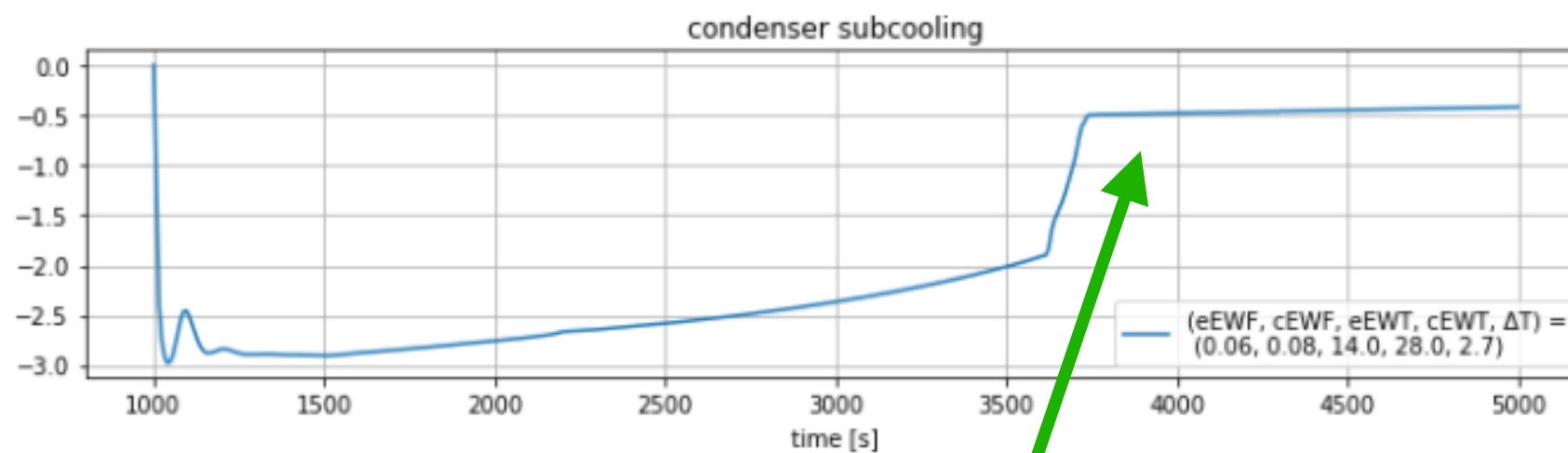subcooling exceeding -0.5

Results from control with LTD

Reaches reference temp of 11.3°C

Feedback term added to counteract subcooling exceeding -0.5

Results from control with LTD

compressor speed (input)

(eEWF, cEWF, eEWT, cEWT, ΔT) = (0.06, 0.08, 14.0, 28.0, 2.7)

valve opening (input)

(eEWF, cEWF, eEWT, cEWT, ΔT) = (0.06, 0.08, 14.0, 28.0, 2.7)

evaporator outlet water temperature [°C]

(eEWF, cEWF, eEWT, cEWT, ΔT) = (0.06, 0.08, 14.0, 28.0, 2.7)

refrigerant pool

(eEWF, cEWF, eEWT, cEWT, ΔT) = (0.06, 0.08, 14.0, 28.0, 2.7)

condenser subcooling
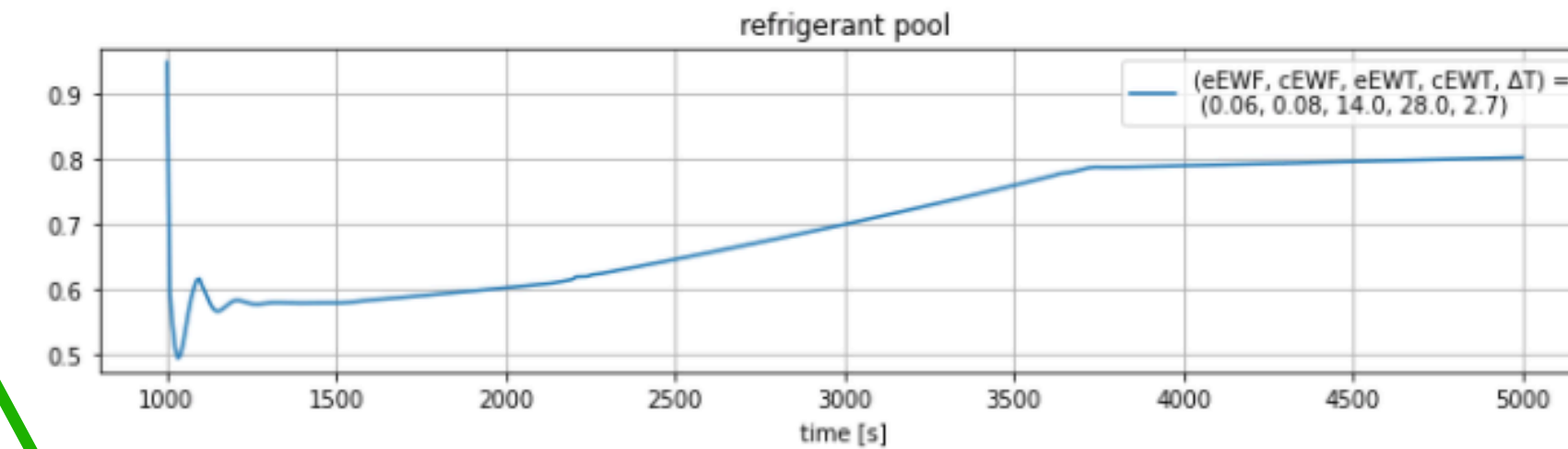
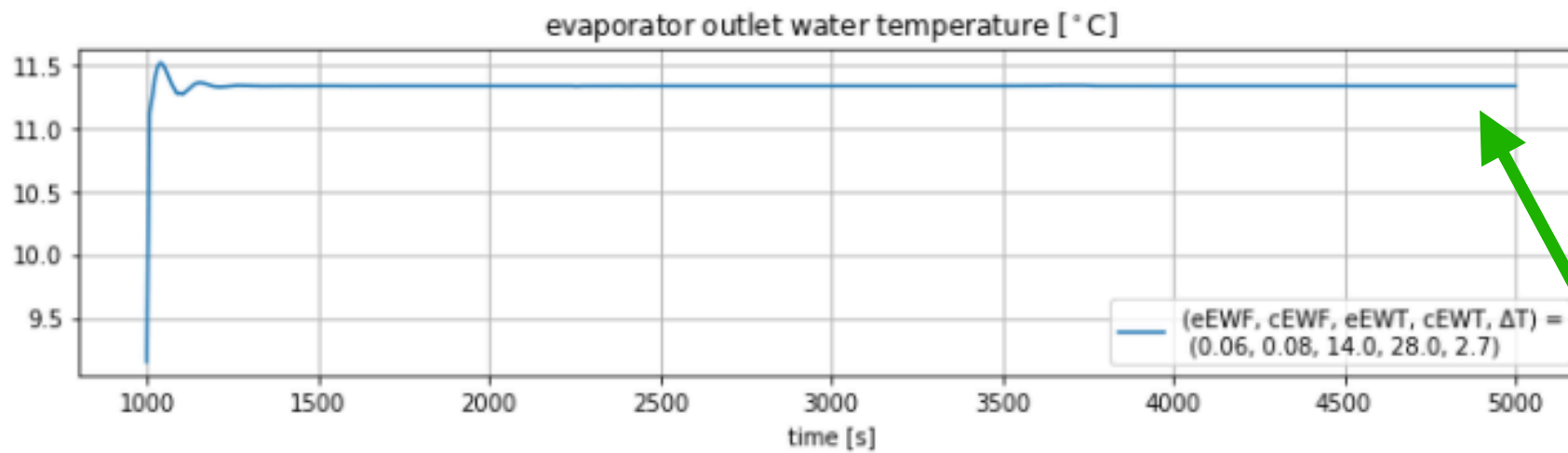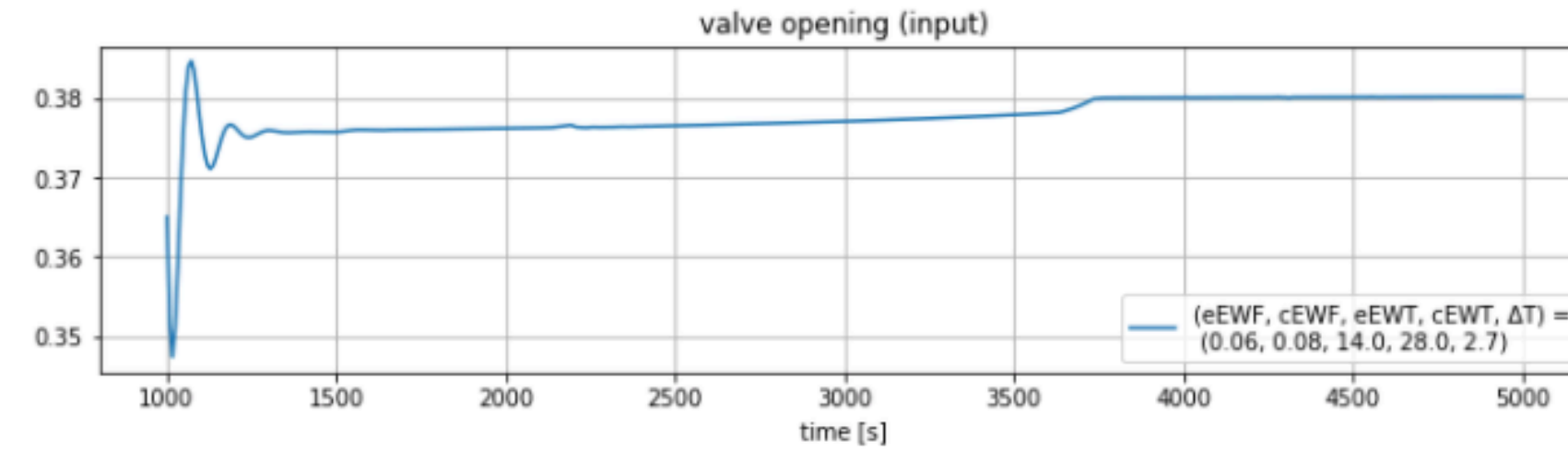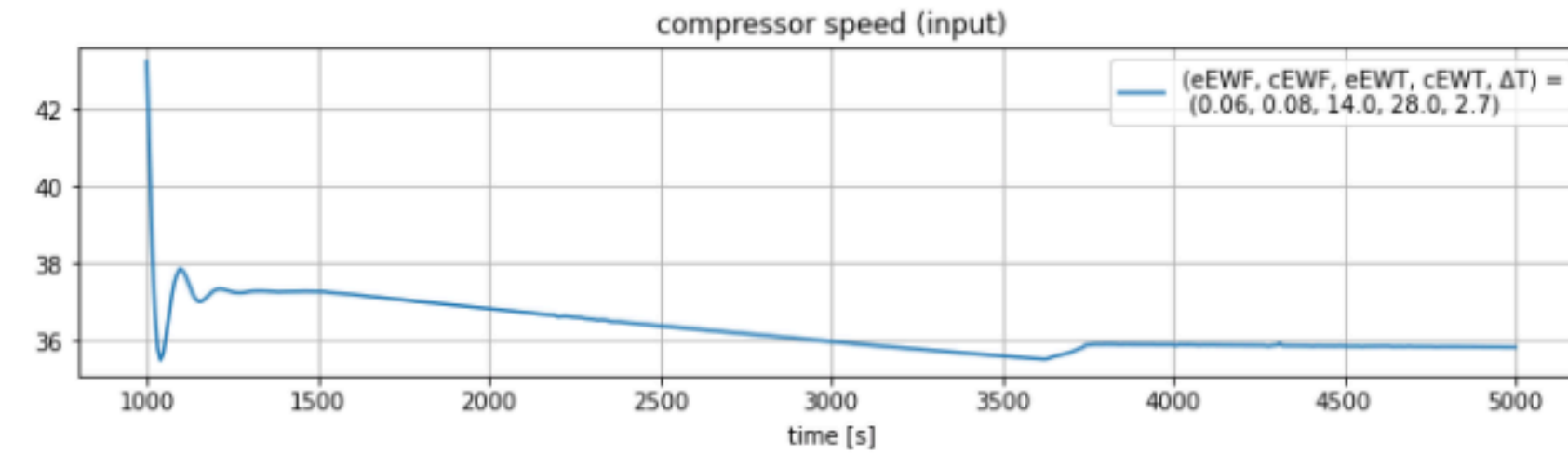(eEWF, cEWF, eEWT, cEWT, ΔT) = (0.06, 0.08, 14.0, 28.0, 2.7)

Reaches reference temp of 11.3°C

Feedback term added to counteract subcooling exceeding -0.5

Works well in this scenario.

(eEWF, cEWF, eEWT, cEWT, ΔT) = (0.06, 0.08, 14.0, 28.0, 2.7)
time = 2336.0: subcool = -2.63, LTD = 2.93, T_suc = 9.33, Tsat_suc = 7.84, Tsat_dis = 34.36, T_dis = 42.65
time = 3672.0: subcool = -1.28, LTD = 2.02, T_suc = 9.77, Tsat_suc = 8.76, Tsat_dis = 34.13, T_dis = 41.62
time = 5000.0: subcool = -0.42, LTD = 1.91, T_suc = 9.80, Tsat_suc = 8.86, Tsat_dis = 34.18, T_dis = 41.58

Chart A-11   R134a *ph* diagram. (*Source:* Based on *Thermodynamic Properties of HFC-134a (1,1,1, 2-tetrafluoroethane)*, DuPont Company, Wilmington, Delaware, 1993, with permission.)

Future work

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- How is the COP (efficiency) affected by different control settings (different feedback signals, parameter values, etc.)?

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- What sensors are worth to add?

- Can we optimize the control adaptively, e.g. by some kind of dual control?

Thanks for listening!