CO_2 Heat Pump Water Chillers

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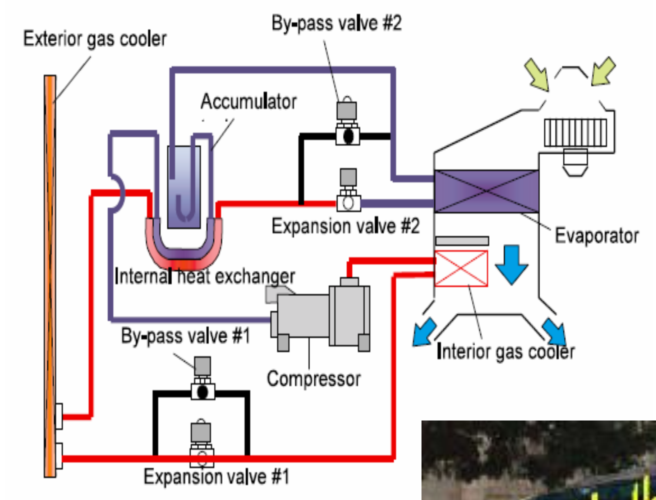
- Benefit of CO_2 chiller heat pumps
- Innovative CO_2 chiller development by ENEX
- The CO_2 Heat Pump Water Chiller within the MultiPACK project
  - Operation modes
  - Test results
- Summary & Conclusion

Introduction: CO_2 heat pump history

2001→ JAPAN: Toyota FCEV vehicle will have CO_2 AC and HP



CO2 Air Conditioning System - page 6
Tokyo Motor Show 2003

Courtesy, Denso

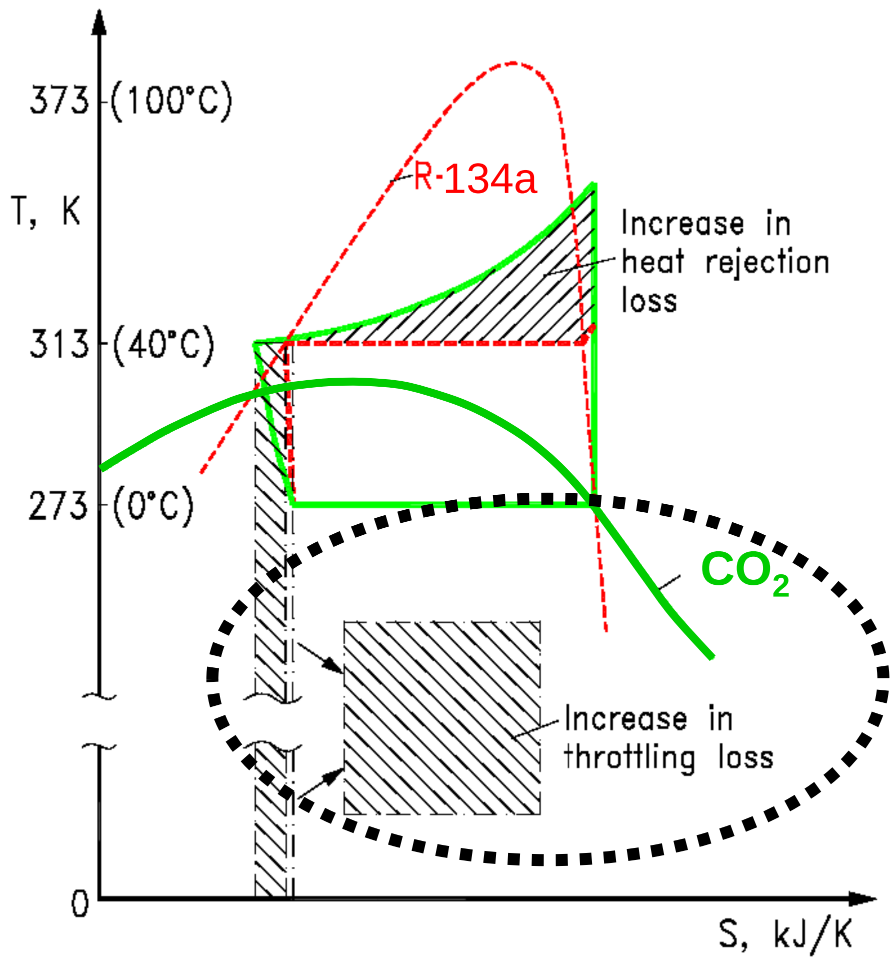
CO_2 Hot water heat pump development start: 1989 (PhD Nekså)

Example from Japan:

- **First <u>EcoCute*</u> system sold: May 2001**
- **→ 1.700.000 units between 2001 and 2008**
- **Up to now: ~ 5.000.000 units installed**

Courtesy, Denso

R-744 (carbon dioxide) as Working Fluid



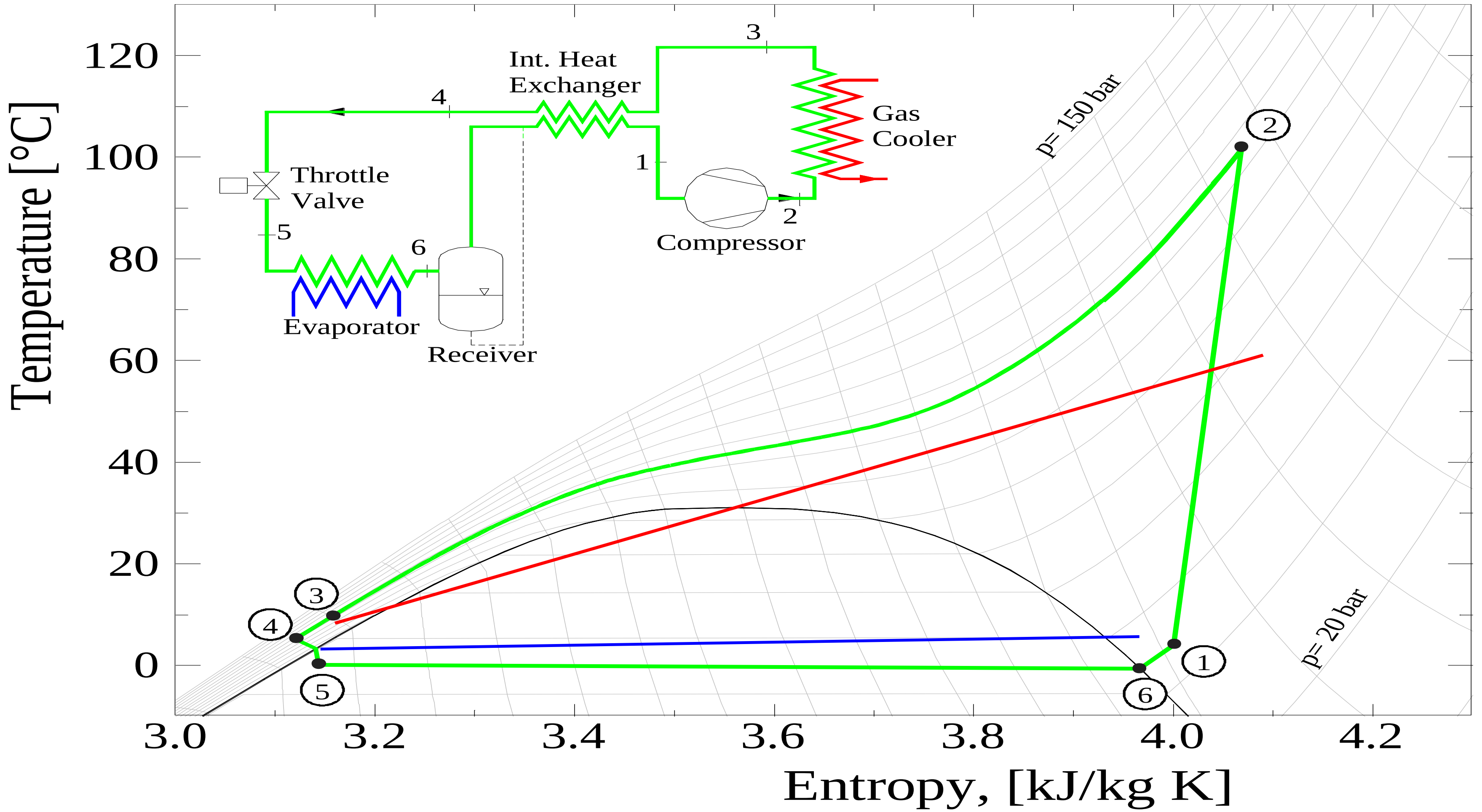
Advantages by applying CO_2 as working fluid:

- safe.
- high refrigerant density → reduced compressor swept volume & small refrigerant lines
- low pressure ratio → high compressor efficiency
- high heat transfer and low specific pressure drop

Challenges:

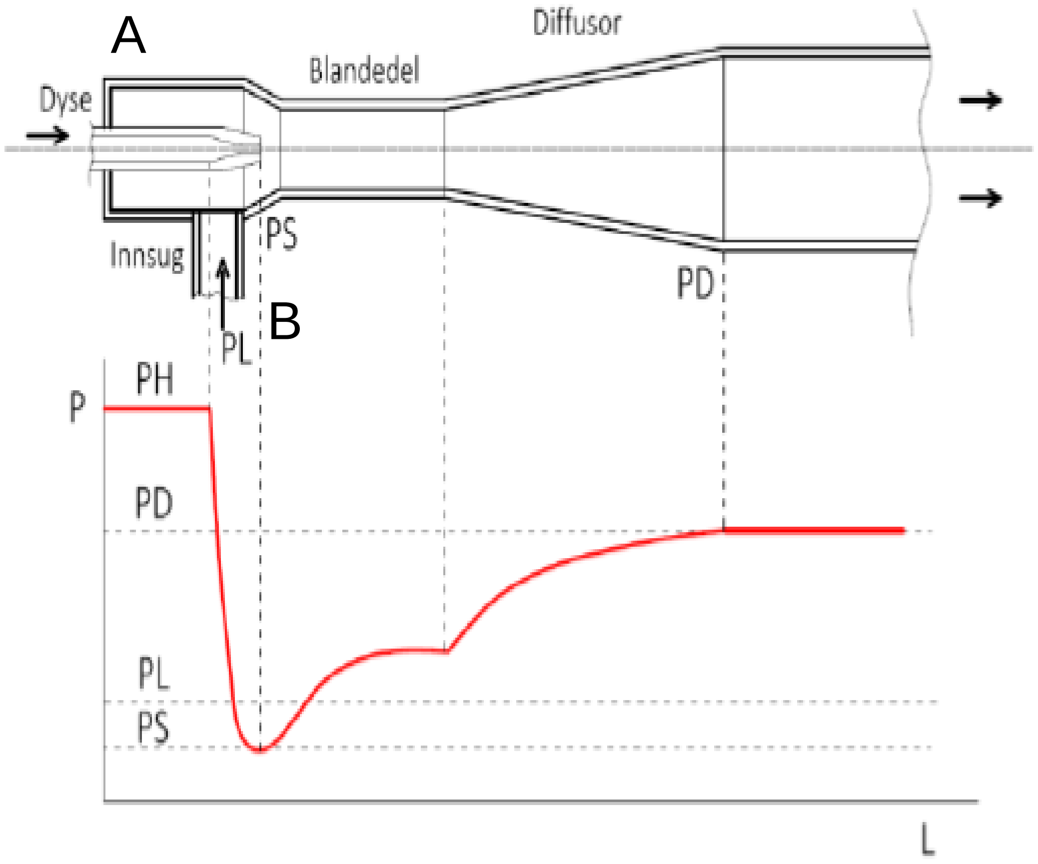
- Increase in heat rejection loss
- Increase in throttling loss

Increase in heat rejection loss → benefit for hot water heating



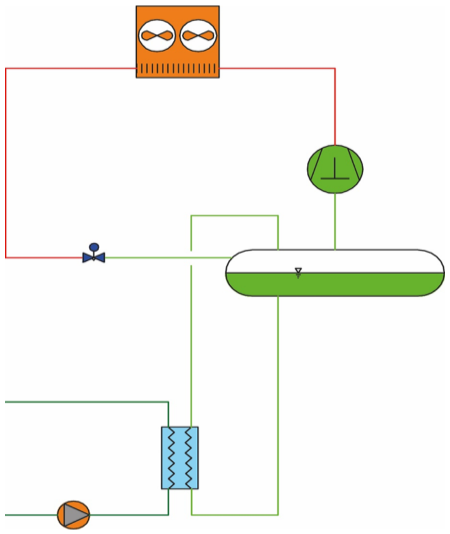
Increase in throttling loss
→ benefit for expansion work recovery: Example ejector

- "Jet pump"
- No additional work required – "Free" pressure lift
- No moving parts: easy to install, operate and maintain
- Bernoulli's Principle: *When the speed of a fluid increases its pressure decreases and vice versa*
  - High pressure fluid enters the nozzle (A) where pressure energy is converted to kinetic energy. Fluid at low pressures (B) is sucked into the nozzle and the two streams are mixed. The pressure increases further in the diffuser as the velocity of the stream decreases.



Timeline of innovative CO_2 chillers by enex

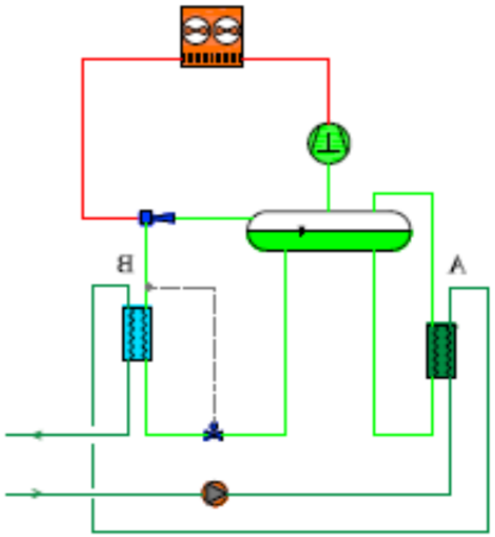
2015



- **Gravity feeding**
- Low ΔT at part load:
- Dynamic set point

→ **robust and reliable**

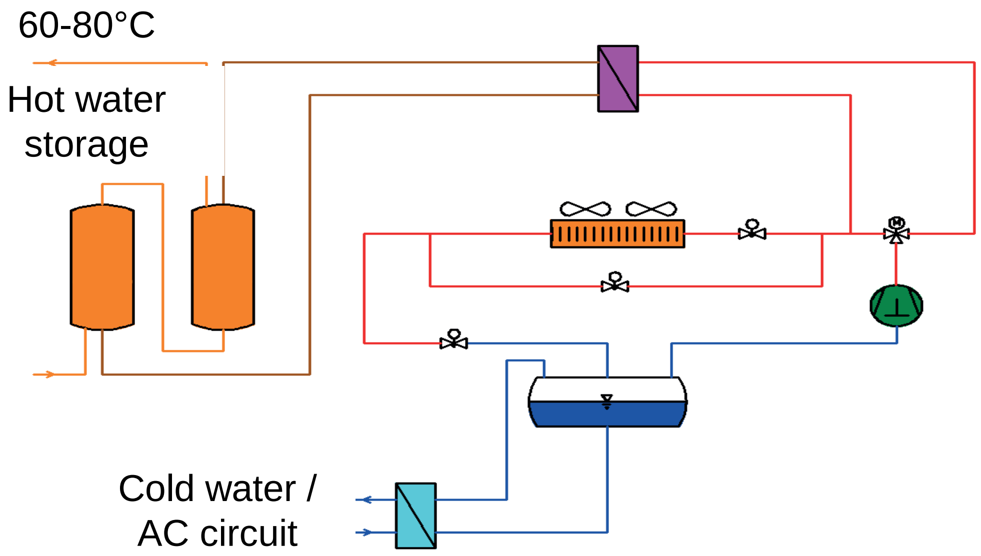
2017



- **Gravity + Ejector** evaps.
- Simple layout and control
- No climate restrictions

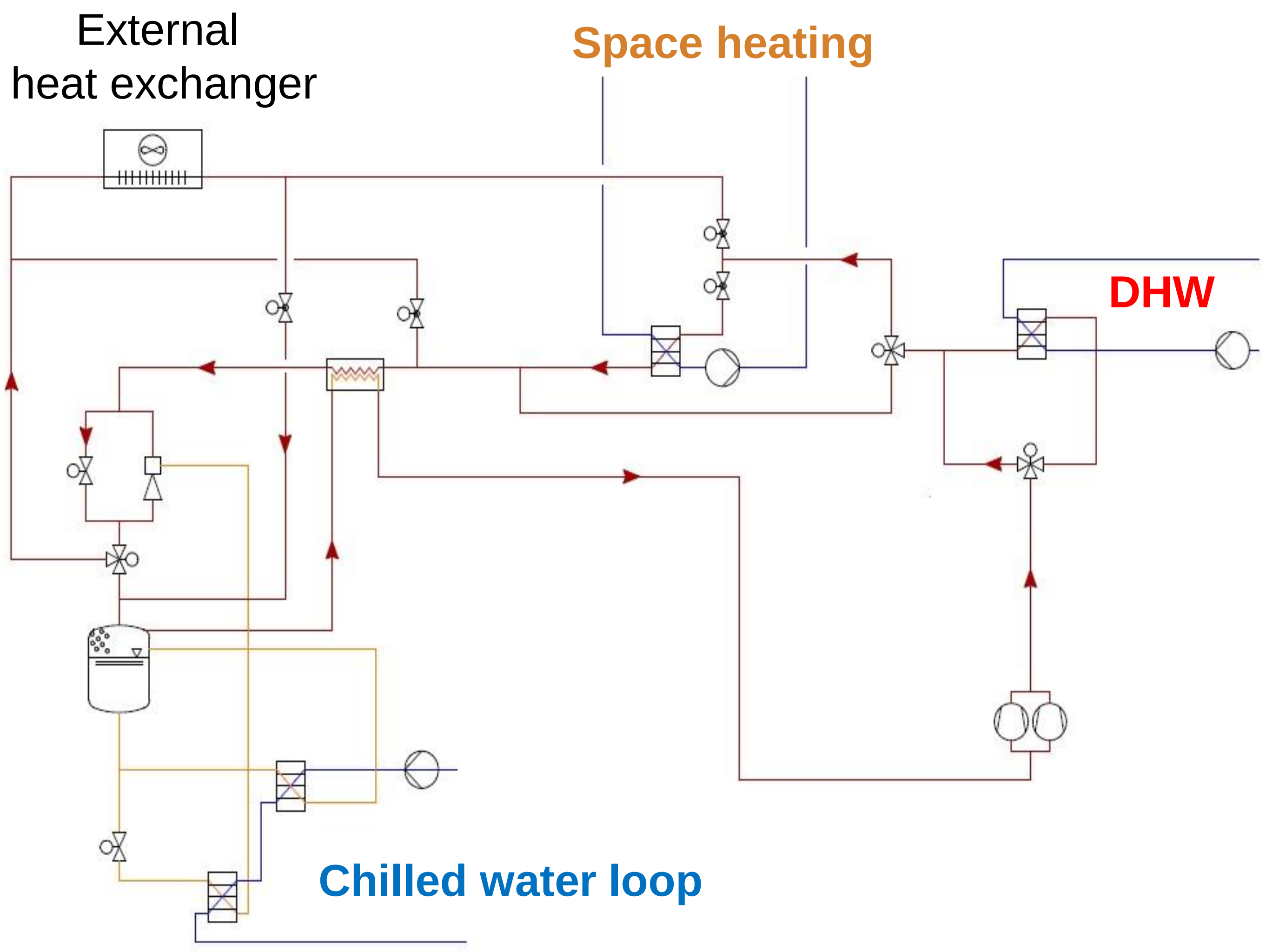
→ **5-15% efficiency gain**

2018



- **Chiller + Heat Recovery**
- DHW and/or space heating
- Gravity (and ejector) evaporator
- High pressure optimization

2020: The ‘CO_2 Heat Pump Water Chiller’

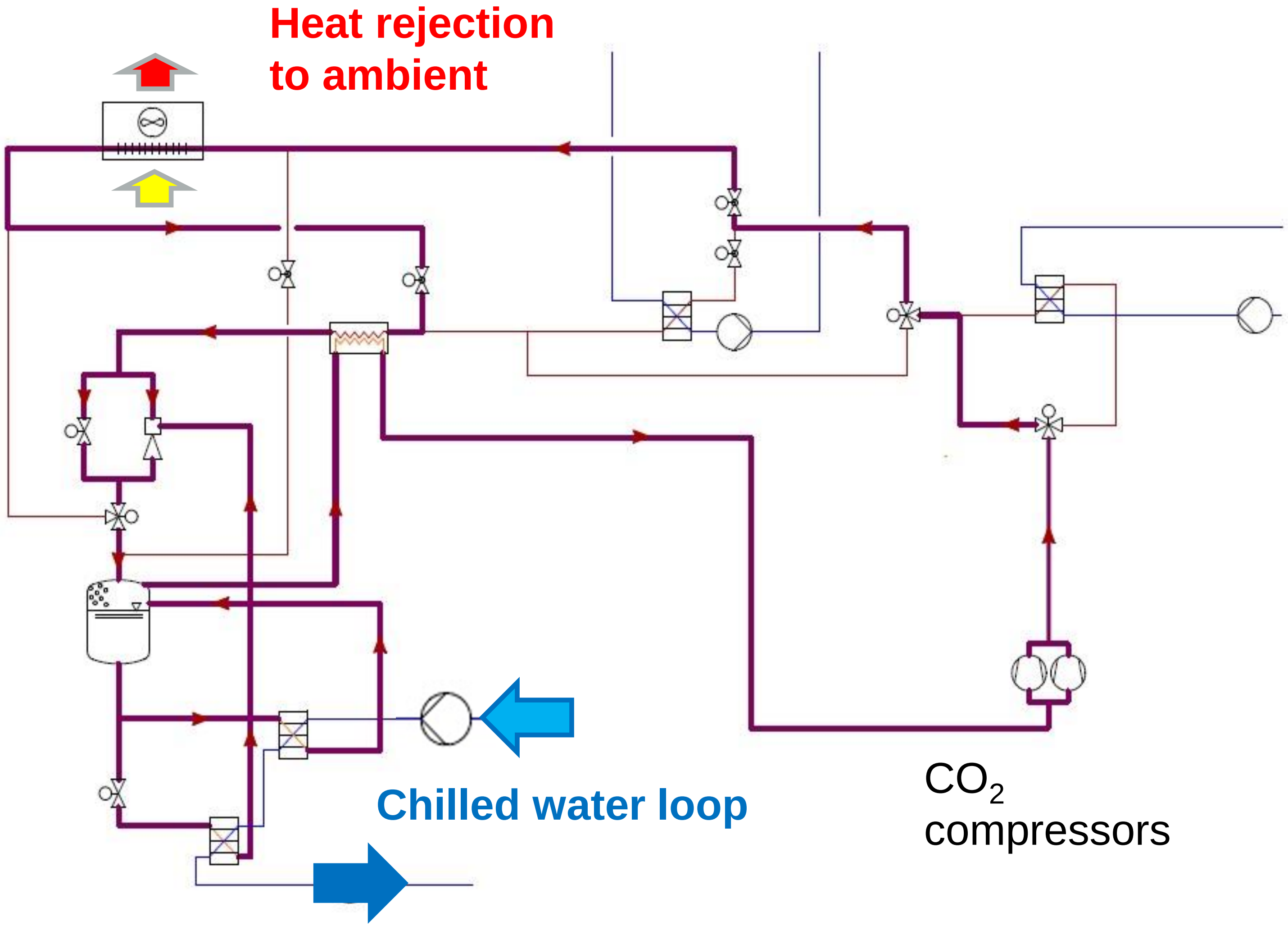


Main features of all-in-one unit:

- Chilled water
- Domestic hot water production
- Space heating
- Air to water heat pump
  - Hot gas defrost
- Non flammable refrigerant (A1)
  - Safe
  - No location restrictions
- Simple and inexpensive installation

The 'CO$_2$ Heat Pump Water Chiller'

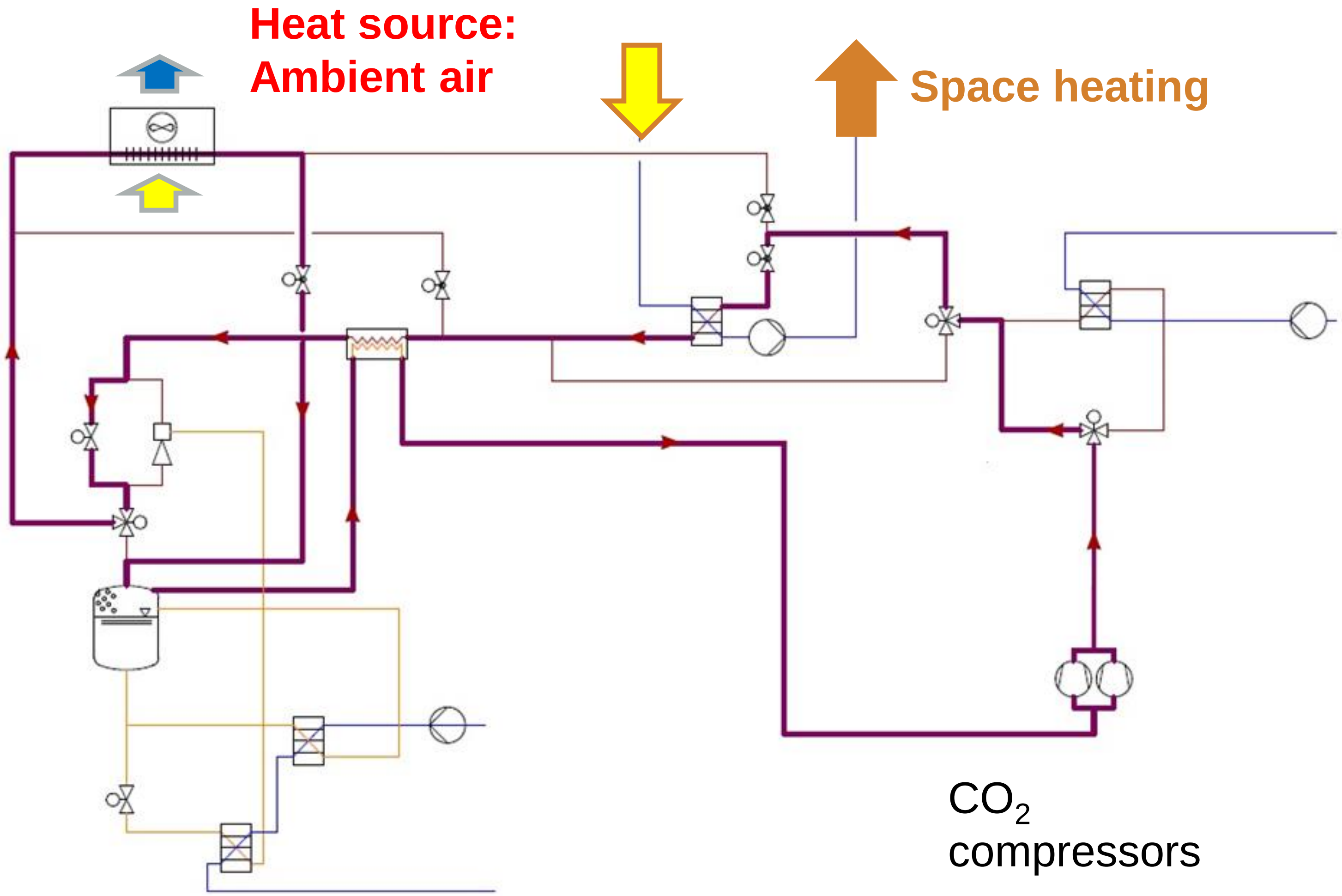
Chiller mode (water / air)



Chiller mode:

- Heat rejection to ambient air
- Gravity + Ejector evaporators

The ‘CO_2 Heat Pump Water Chiller’
Heat pump mode (air / water)

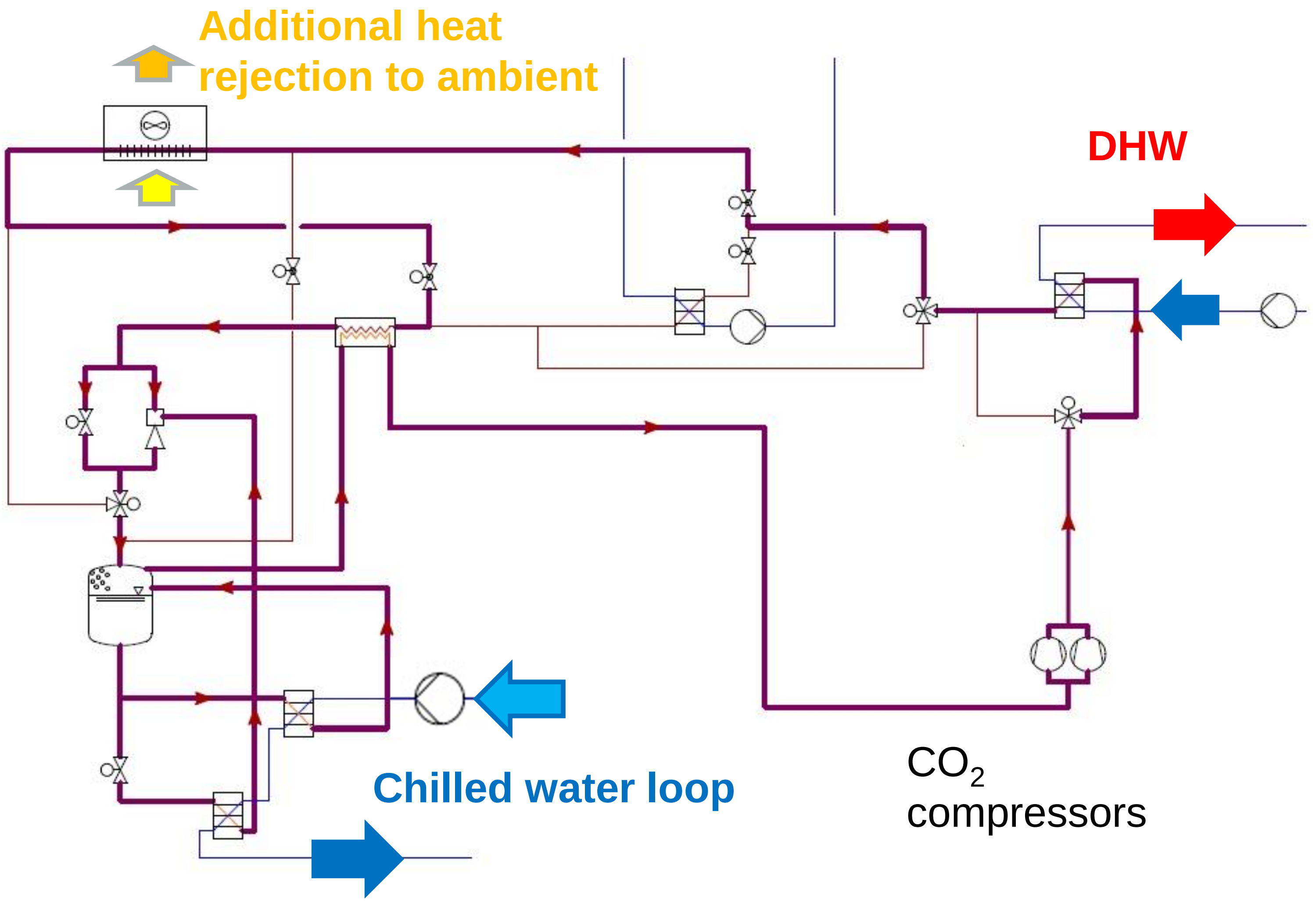


HP mode (space heating):

- Air as heat source
- Classic low pressure receiver CO_2 circuit
- Optional:
  - simultaneous production of DHW in addition to space heating

The 'CO$_2$ Heat Pump Water Chiller'

Chiller + DHW mode (water / water)



Chiller + DHW mode:

- Gravity + Ejector evaporators
- DHW production
- Partly heat rejection to ambient
  - function of cold water inlet temperature
- Optional:
  - simultaneous supply of heat for space heating

Test results of the ‘CO_2 Heat Pump Water Chiller’

MultiPACK supported demonstration unit tested in workshop prior commissioning

- **Fully instrumented:**

  Temperatures, Pressures, Thermal Capacities, Electrical Power, Flow meters (CO_2 side)
- **Controlled boundaries:**

  Water temperature and flow rate
- **Uncontrolled boundaries:**

  Air temperature (outdoor air as heat source/sink)

Test results of the ‘CO_2 Heat Pump Water Chiller’

Chiller circuit

DHW circuit

TEST 1: high load

- 2 comp ON – inverter 50Hz
- High pressure: 99 bar
- Temp out GC: 38.5°C
- COP: 4.9
- Power El: 49 kW

t_{in} water	t_{mid} water	t_{out} water
14.1 °C	11.1 °C	6.8 °C
Q_o Tot	$Q_{ev\ gravity}$	$Q_{ev\ ejector}$
104 kW	43 kW	61 kW

t_{in} DHW	t_{out} DHW
30.0 °C	60.0 °C

Q DHW
132 kW

TEST 2: low load

- 1 comp ON
- High pressure: 94 bar
- Temp out GC: 36.5°C
- COP: 5.3
- Power el: 23 kW

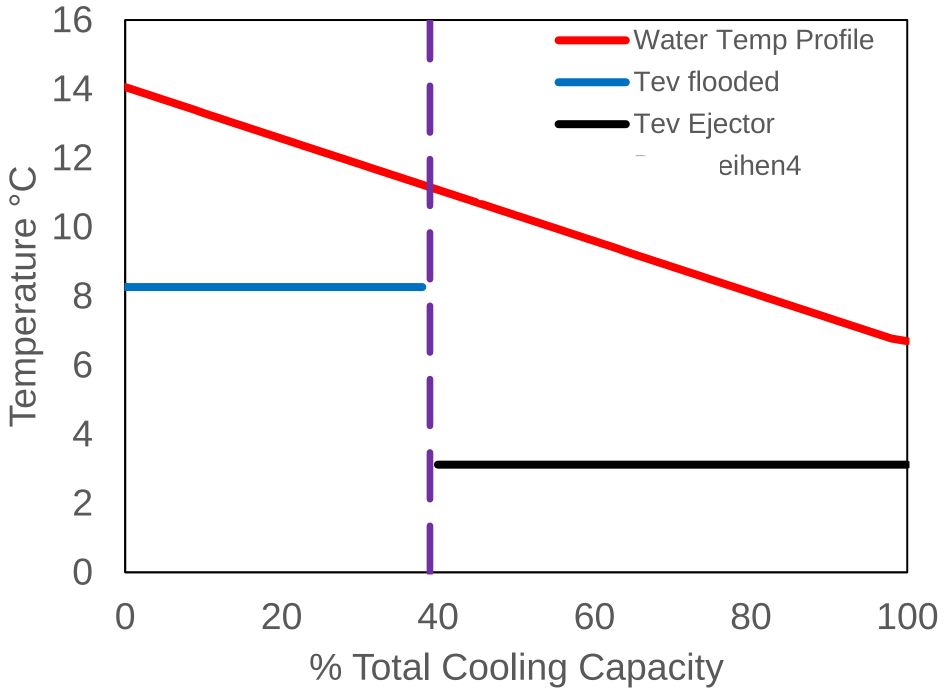
t_{in} water	t_{mid} water	t_{out} water
11.0 °C	9.0 °C	7.0 °C
Q_o Tot	$Q_{ev\ gravity}$	$Q_{ev\ ejector}$
60 kW	30 kW	30 kW

t_{in} DHW	t_{out} DHW
30.0 °C	60.0 °C

Q DHW
67 kW

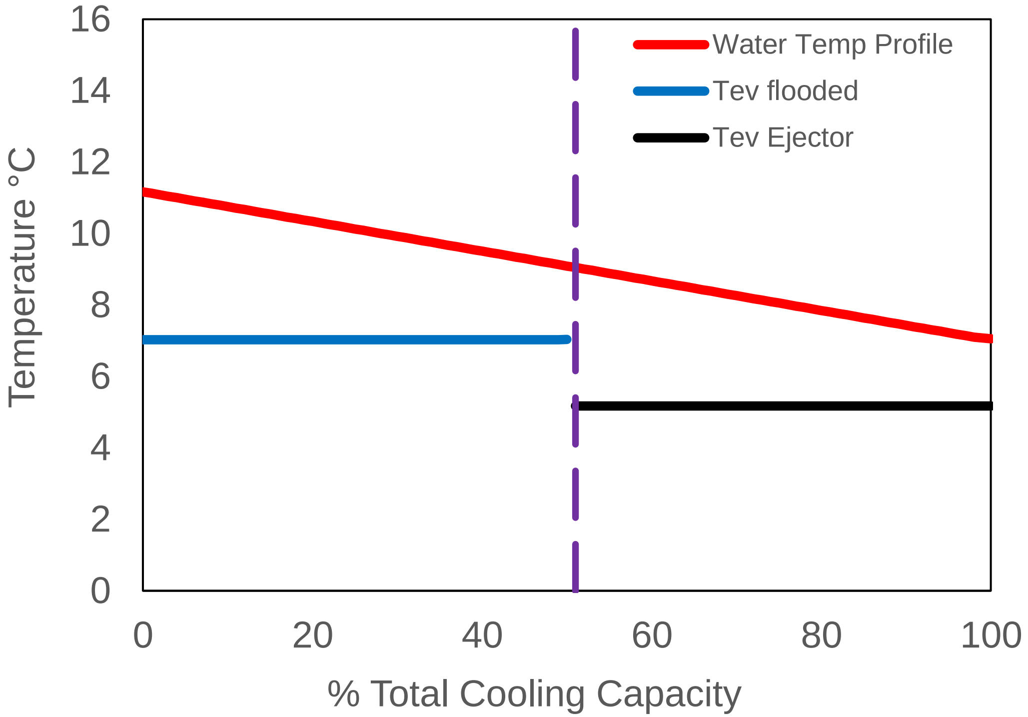
Test results of the ‘CO_2 Heat Pump Water Chiller’

TEST 1: high load



Estimated energy savings *: +10 %

TEST 2: low load

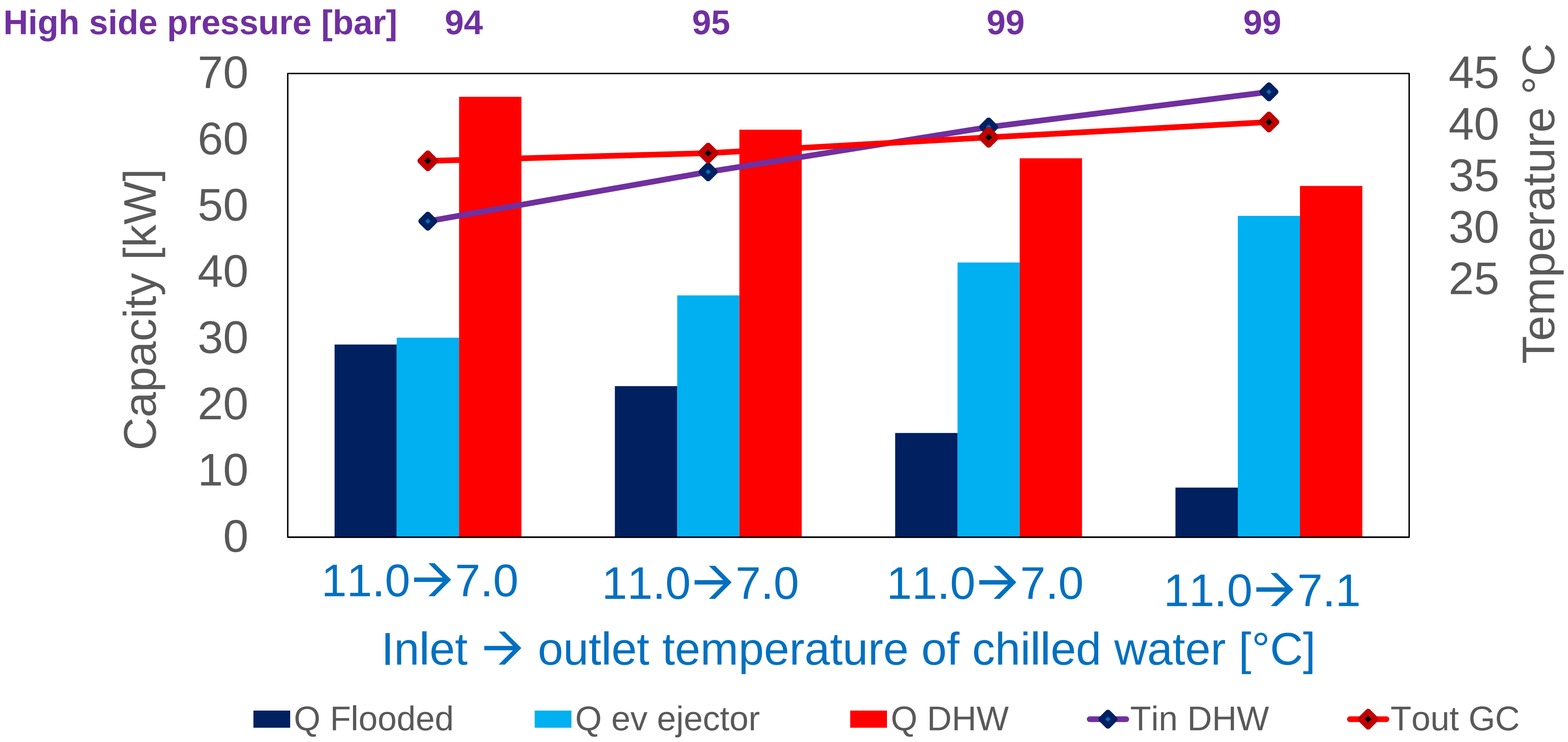


Estimated energy savings *: +7 %

Greater benefit achievable in the case of larger water Δt (especially for process chillers)

* Compared to «only gravity» evaporator with the same total heat transfer area

Test results of the ‘CO_2 Heat Pump Water Chiller’



Summary: ‘CO_2 Heat Pump Water Chiller’

- **CO_2 chillers** are available and are a safe **option for the global market**
- The design of the MultiPACK water/unit is **completely defined**;
- The **control logic** has been optimised with an extensive test campaign;
- **Tests** for performance measurements and feedbacks to the control unit are **continuing**;
- **Field data** for chiller and chiller+DHW operations will be soon available;
- **A transient numerical model** is under development and validation against experimental data;
- The model will be used for **control logic testing** and **performances prediction** under variable boundary conditions.

Conclusion

- Smart integration of **Ejector technology** improves the energy efficiency of CO_2 units, especially chiller units (higher temperature glide)
- **Safety of service people** and end-users should have the highest priority, beside the total environmental impact when selecting the technology and working fluid
- **CO_2 systems are successfully** introduced into some markets
- **Training and knowledge** transfer is the key for a successful and fast phase in of natural working fluid based refrigeration and heat pump units
- World Bank and multi-lateral funds should **support and cover additional first costs with affordable loans**, so the end-users can return the loan during the operational phase. New energy efficient systems applying natural working fluids result in significant OPEX saving

Thanks for your attention, questions are welcome.

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What is a MultiPACK reversible chiller/heat pump?

- An **integrated unit** providing **Heating**, **Air Conditioning** and **DHW**, based on **Carbon Dioxide** as the refrigerant, with air or water as heat source/sink
- Combining **ejectors** and **gravity evaporators** for performance improvement
- Scalable and adaptable to different load ratios and HVAC design
- **Fully instrumented** for performances monitoring

What are the MultiPACK objectives?

- **Prove** technical feasibility, reliability and serviceability
- Build up **confidence**
- **Demonstrate** energy performances in the field

The MultiPACK Project

multi PACK

https://www.ntnu.edu/multipack

- EU funded Horizon 2020 Project (Grant number 723137)
- Duration: 48 months
- Partners: NTNU (coordinator), Sintef, Danfoss, **Enex**, **CNR-ITC**, Sonae, RACE

  partners are present in all the links of the value chain from initial innovation to the actual end user

– Main focus areas:

  - Supermarkets
  - **High energy demanding buildings** (hotel, gyms, etc.)

NTNU

SINTEF

Danfoss

enex
Leading in refrigeration

ITC

SONAE MC

RACE