# $CO_2$ TECHNOLOGY – An Overview

René Rieberer

Institute of Thermal Engineering
Graz University of Technology
Inffeldgasse 25 / B
A 8010 Graz, Austria

http://www.iwt.tugraz.at
rene.rieberer@tugraz.at

# Outline

- Legal Status
- $CO_2$ compared to other Refrigerants
  - Properties
  - Refrigerant Cycle and Characteristic
- Heat Pumps
  - Heat Pump Water Heater
  - Hydronic Heating System + HPWH
  - Heat Pump Dryer
  - Thermosyphon Heat Source System
- Examples for Further Applications
  - Automotive AC and HP
  - Secondary Loop
- Outlook

# Legal Status

EU: - Stationary Applications: 'restricted' use of fluorinated greenhouse gases

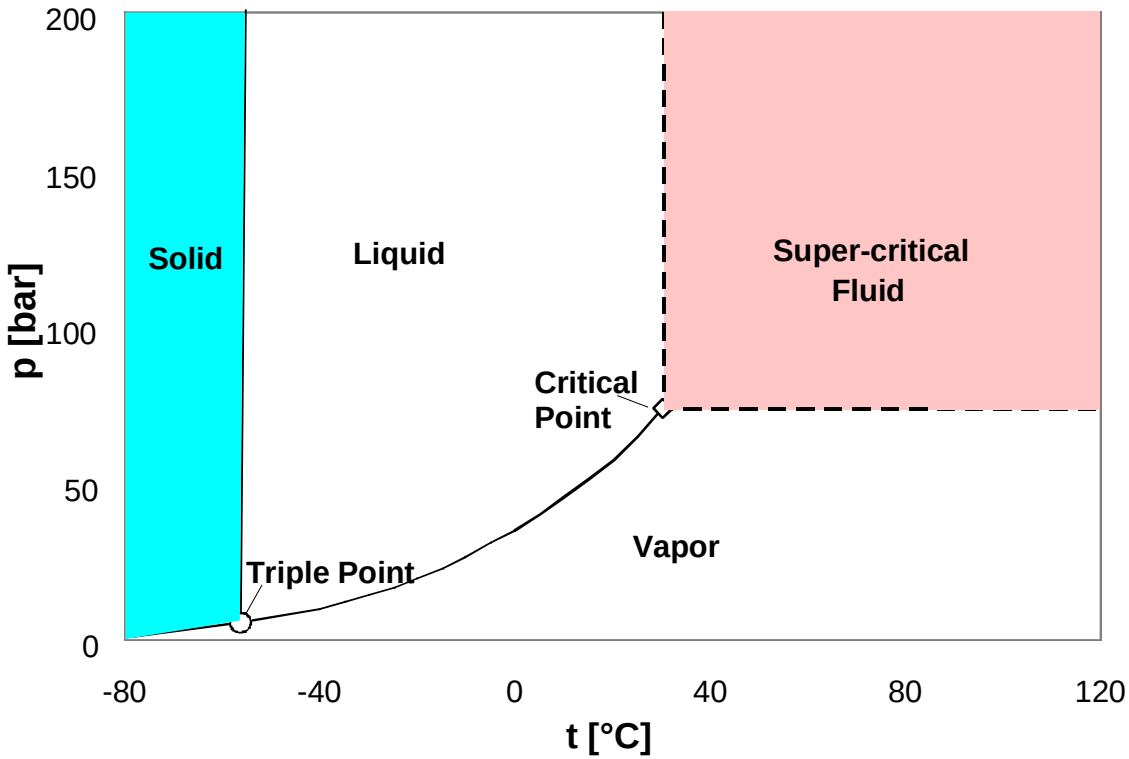
- Automotive air conditioning systems: ban of refrigerants with a GWP > 150

Status: second reading in the EU Parliament passed (Oct. 26,2005)
Environm. Council should agree on Dec. 2, 2005

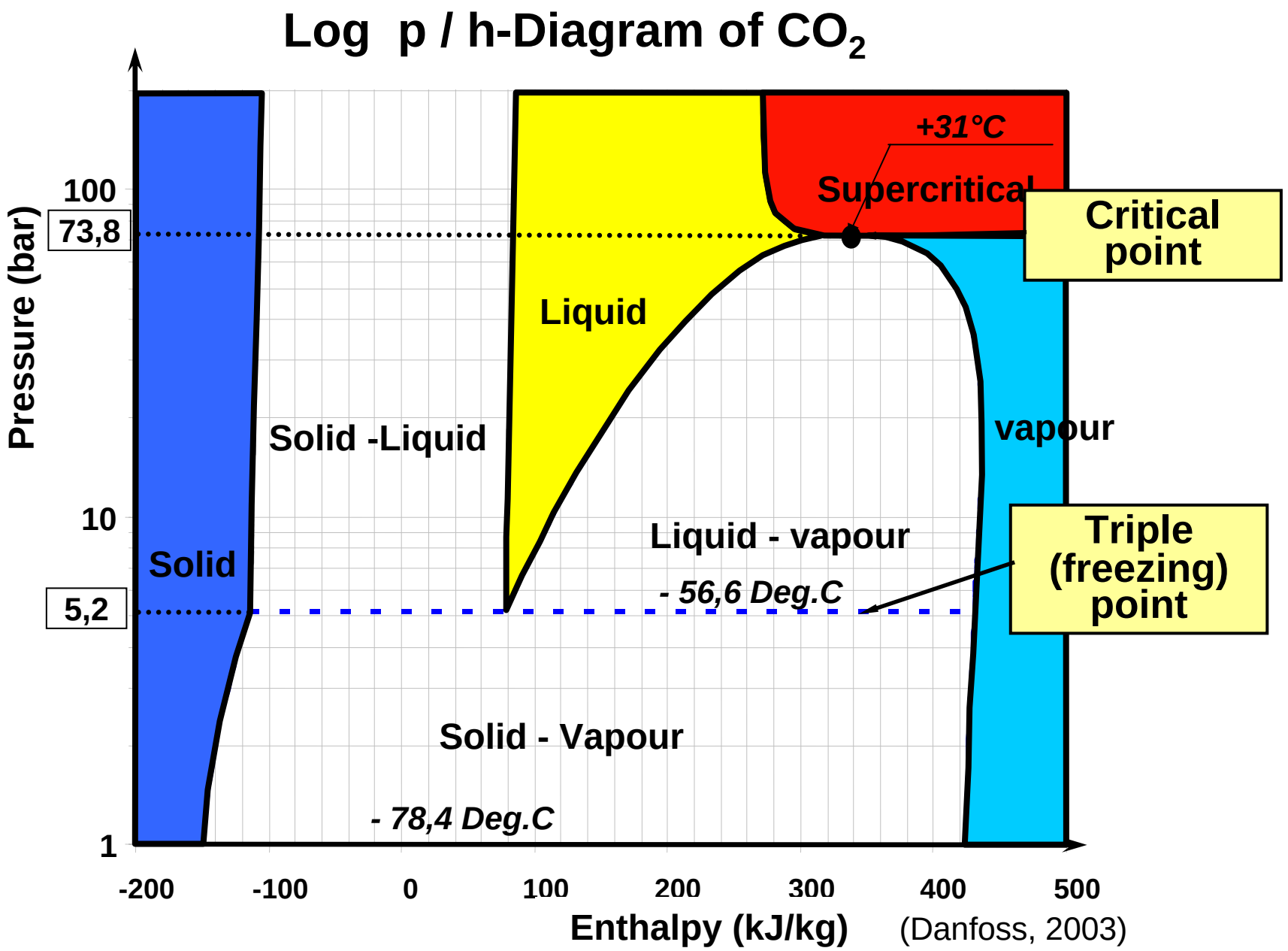
Austria: 2008 ban of HFCs in new equipment (Status of a regulation from Dec. 10, 2002)

# Properties of $CO_2$ (R744)

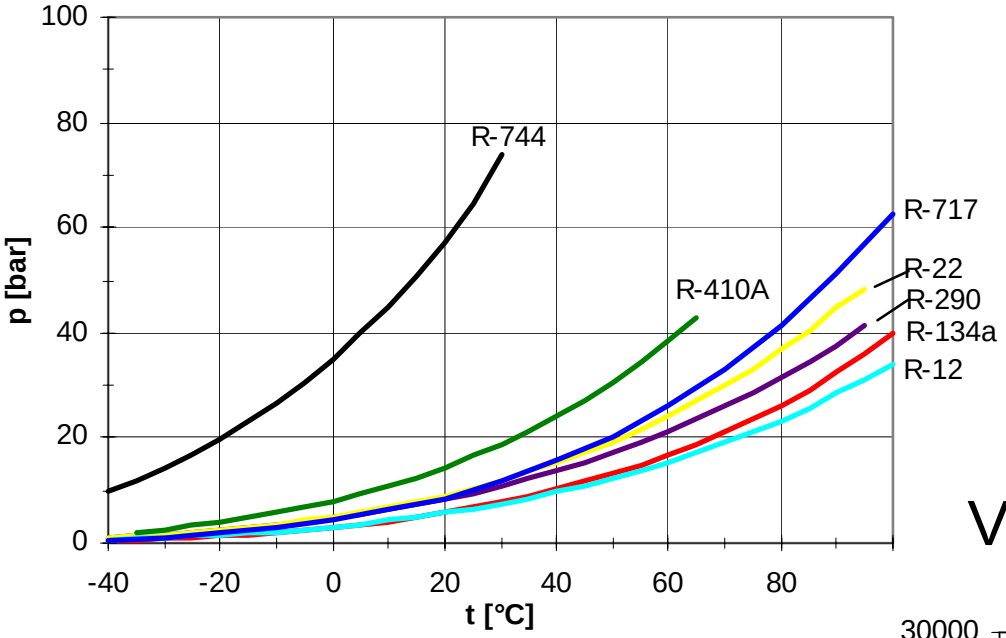
+ Natural Substance
+ Non toxic
+ Non flammable
+ Cheap (waste product)
+ GWP = 1
+ ODP = 0



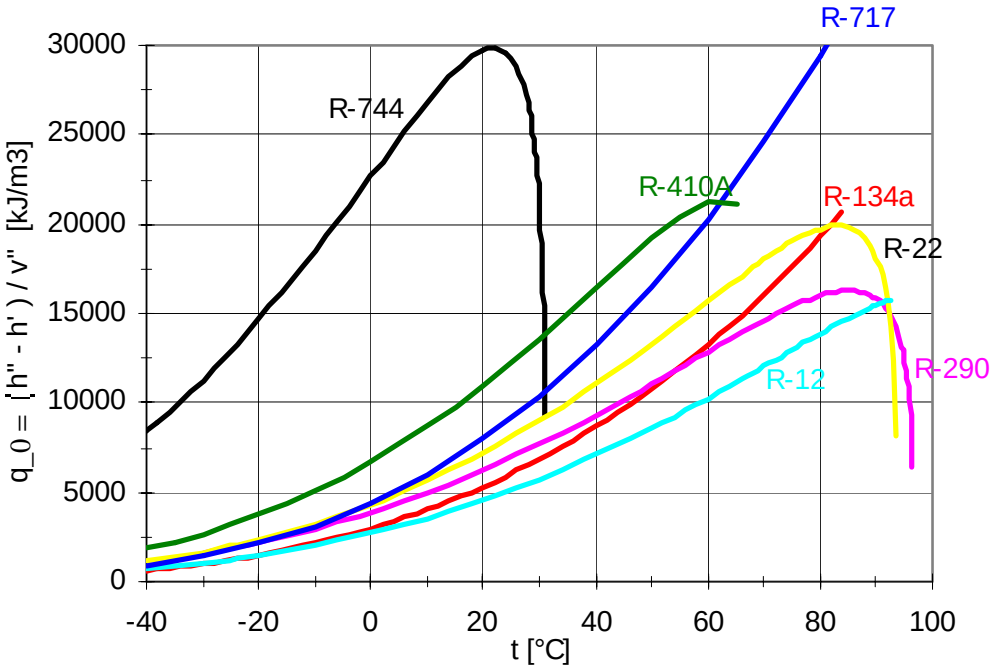

+ Low critical temperature (31°C) / high critical pressure (73 bar)


Log p / h-Diagram of $CO_2$
Pressure (bar)
100
73,8
10
5,2
1
+31°C
Supercritical
Critical point
Liquid
Solid -Liquid
vapour
Liquid - vapour
- 56,6 Deg.C
Triple (freezing) point
Solid
Solid - Vapour
- 78,4 Deg.C
-200
-100
0
100
200
300
400
500
Enthalpy (kJ/kg)
(Danfoss, 2003)

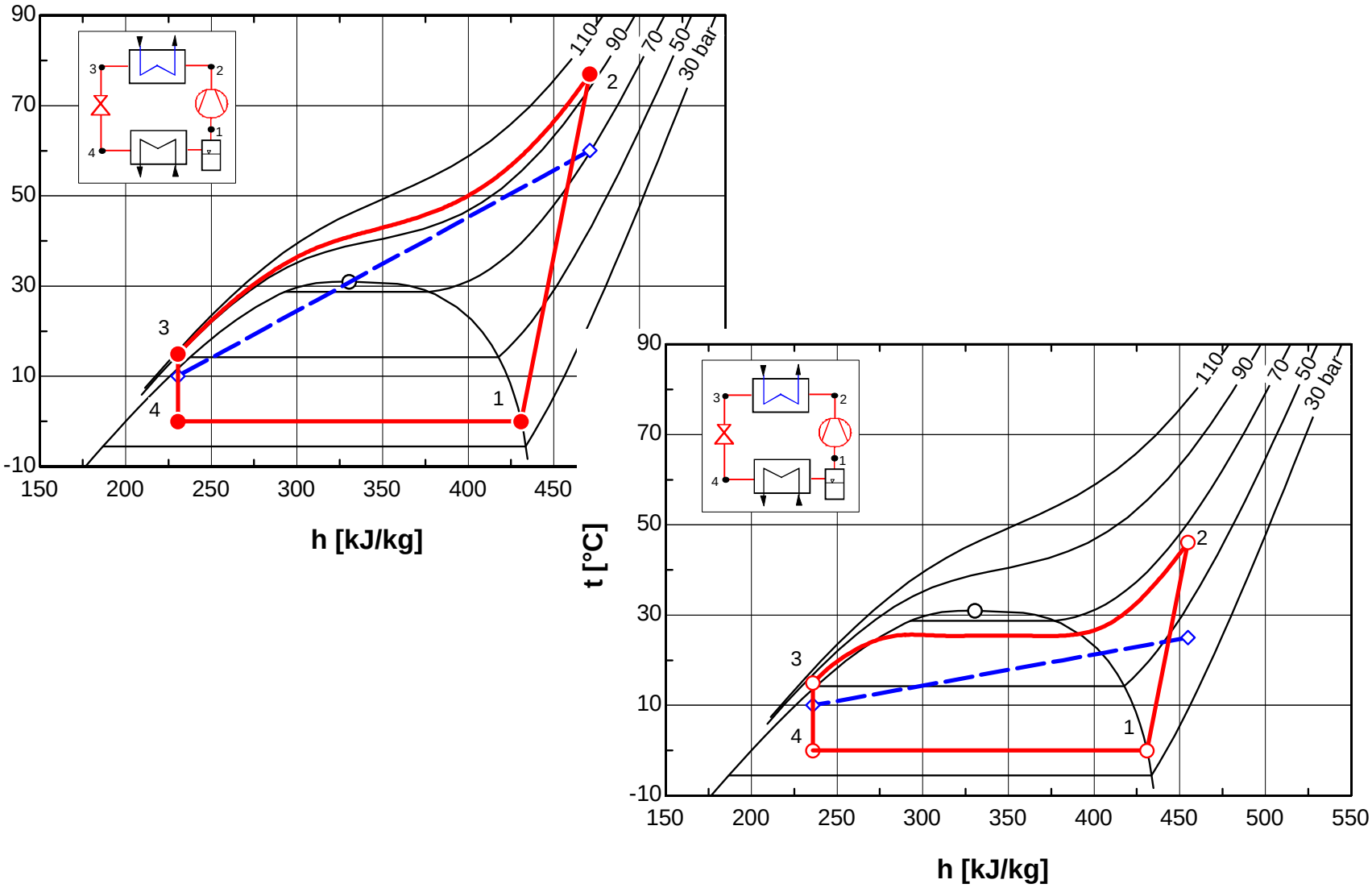
# Saturation Pressure



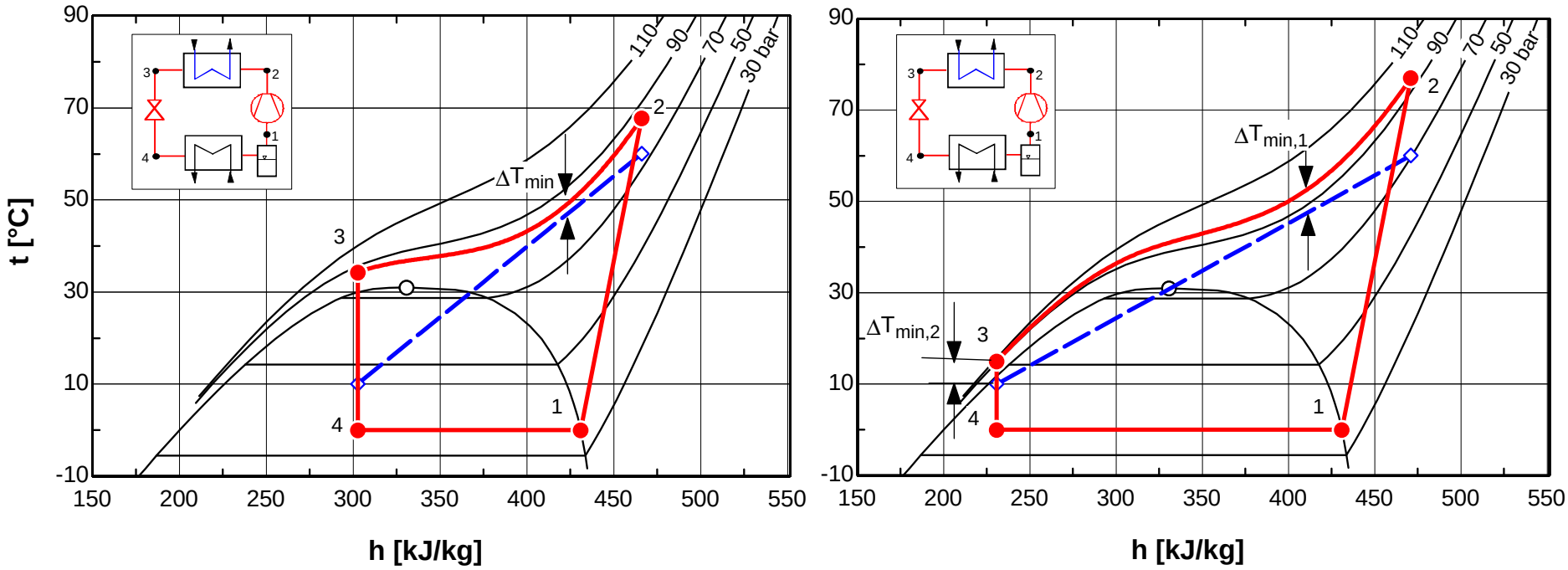

# Volumetric Cooling Capacity



# $CO_2$ Cycle

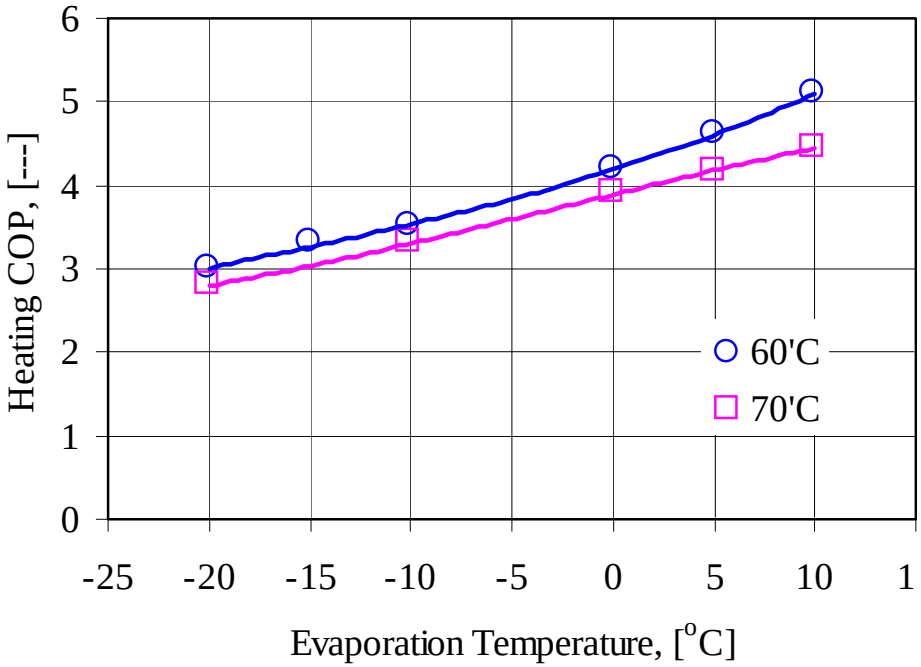

90
70
50
30
10
-10
150
200
250
300
350
400
450
500
550
110
90
70
50
30 bar
1
2
3
4
t [°C]
h [kJ/kg]

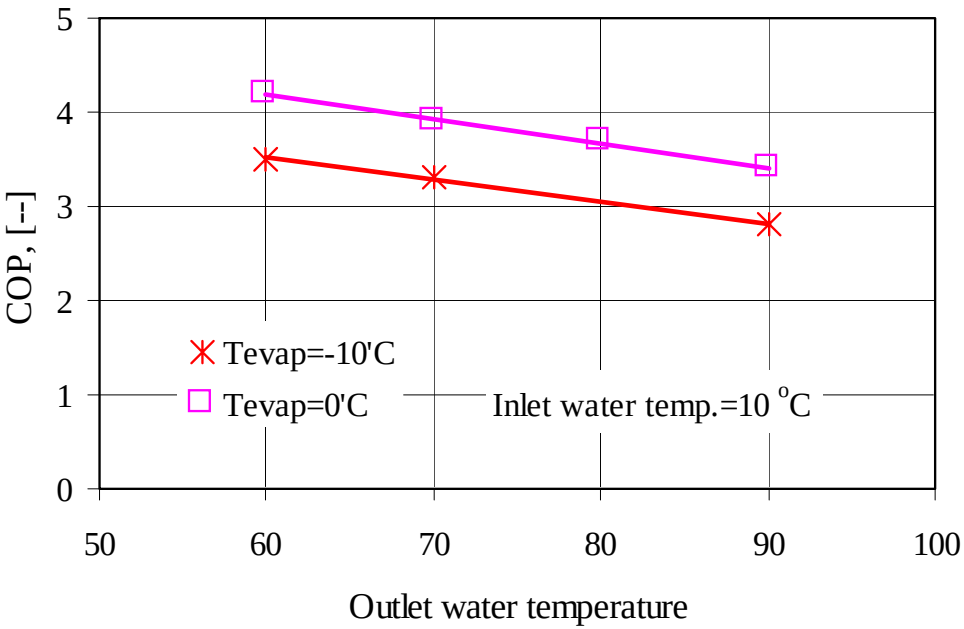
# $CO_2$ Cycle




**COP_max at the optimum high-side pressure**

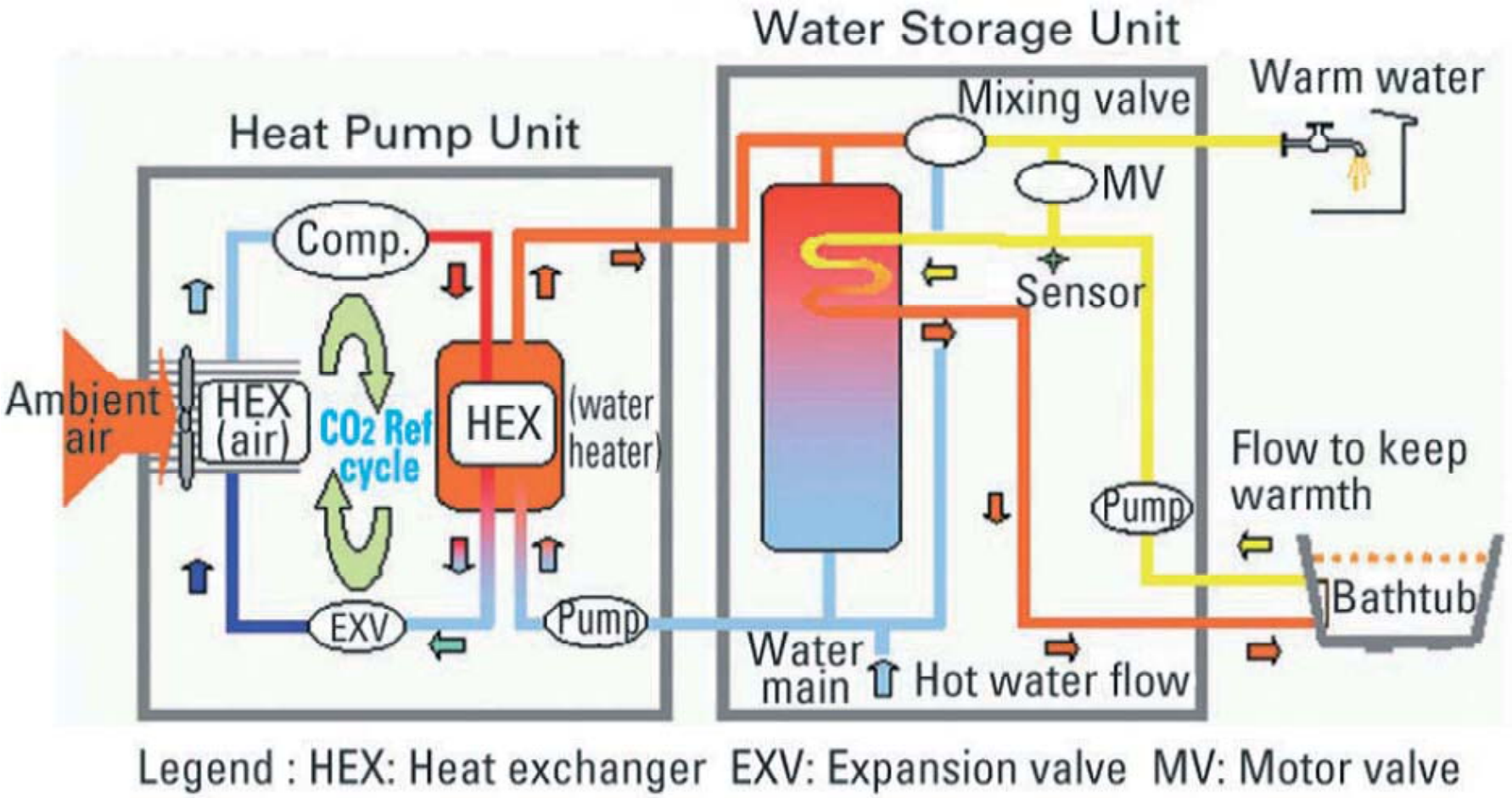
# Application – Heat Pump Water Heater




(Nekså et al, 1999)

# Heat Pump Water Heater



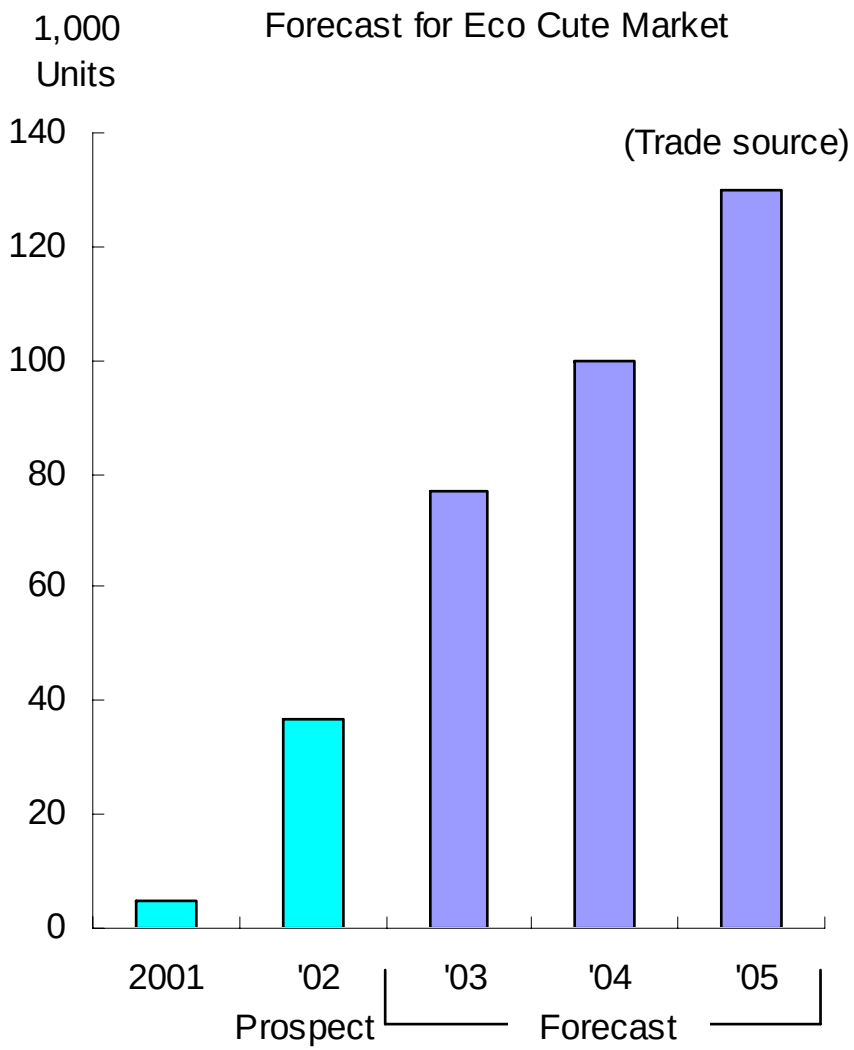

http://www.jarn.co.jp

# Heat Pump Water Heater



Denso

# Heat Pump Water Heater

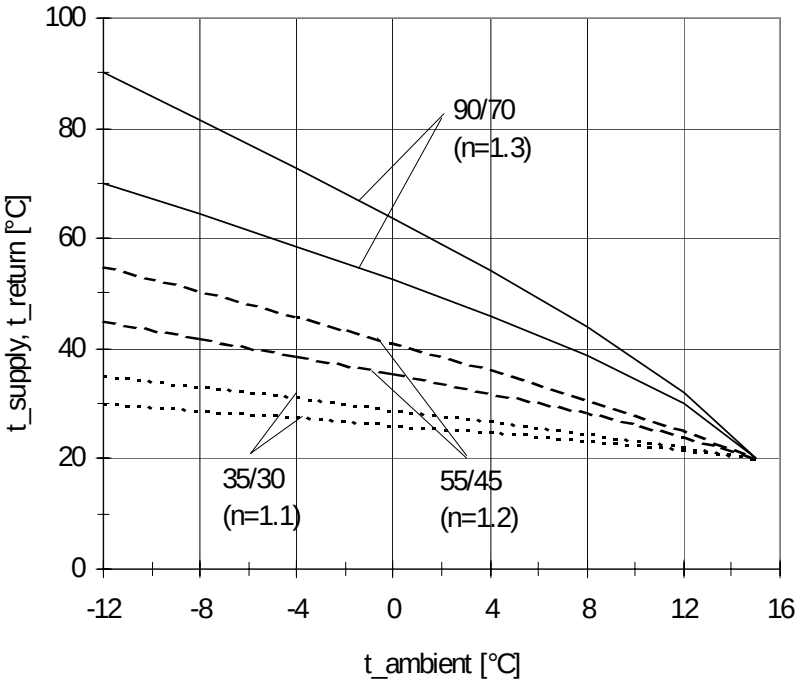


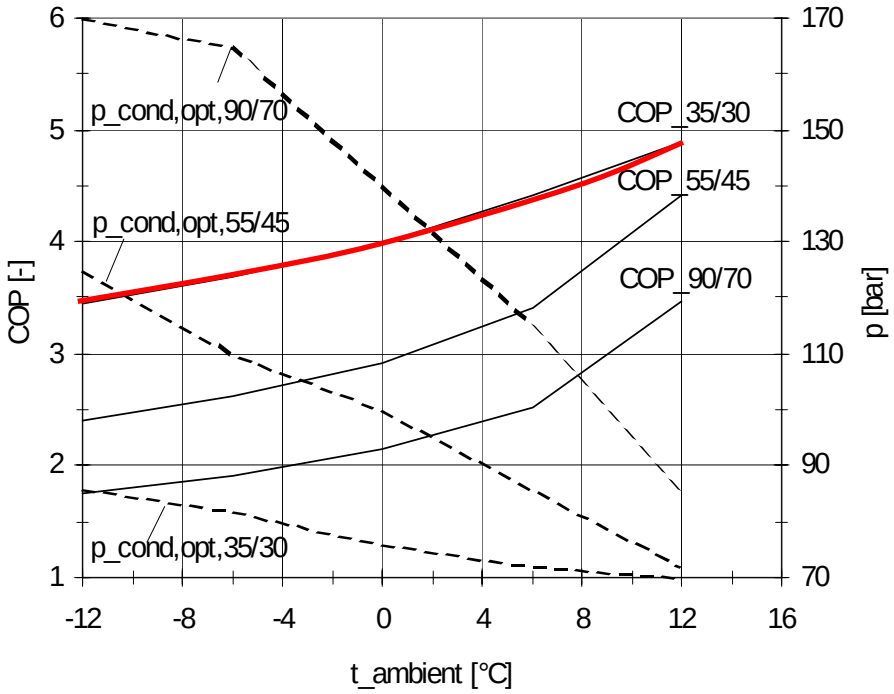

http://www.jarn.co.jp

# $CO_2$ Heat Pump Water Heater in Austria

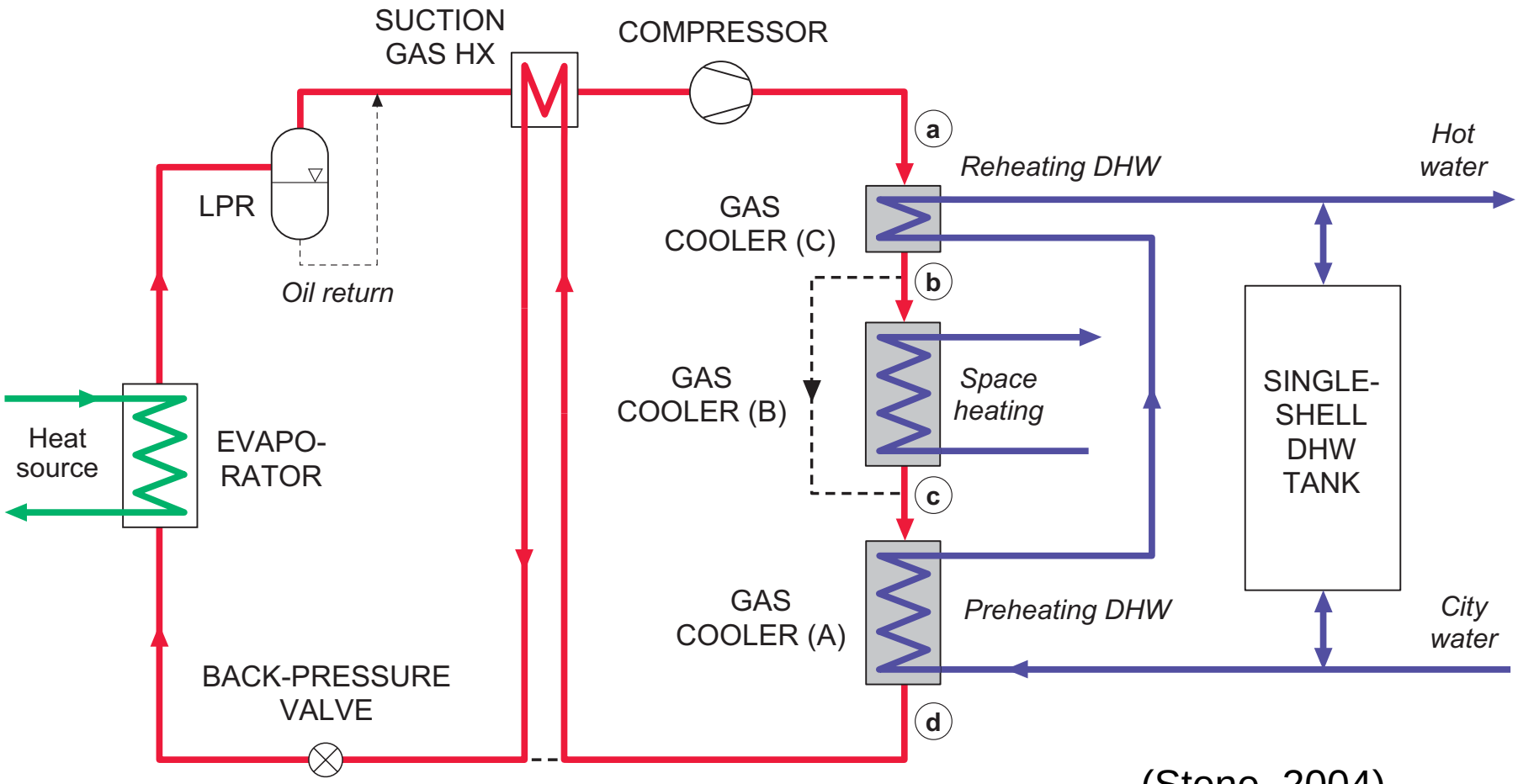
+ Test rigs available
+ Product development at different SME
+ Market introduction?

# Application – Hydronic Heating System



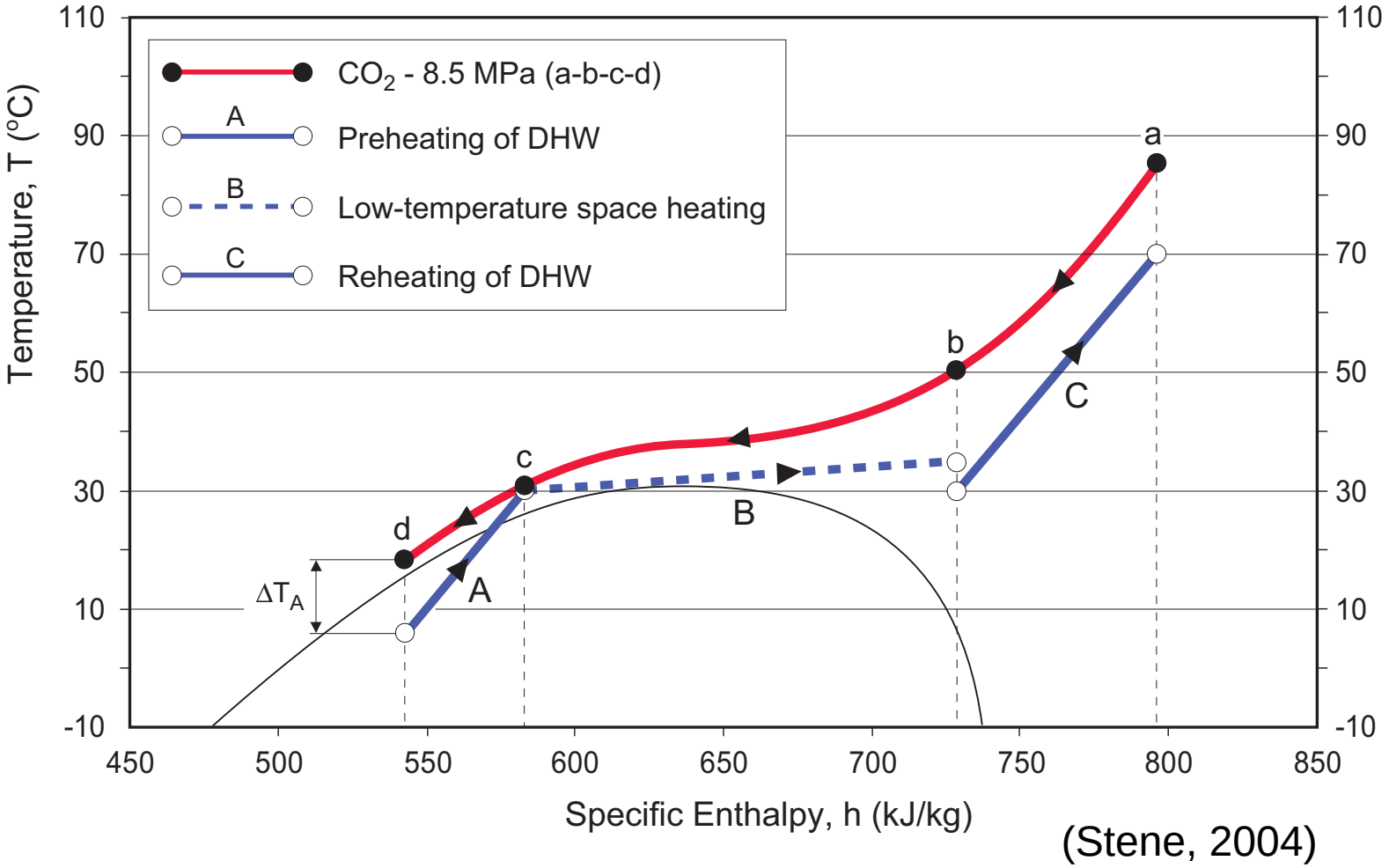



# Application – HPWH + Hydronic Heating System



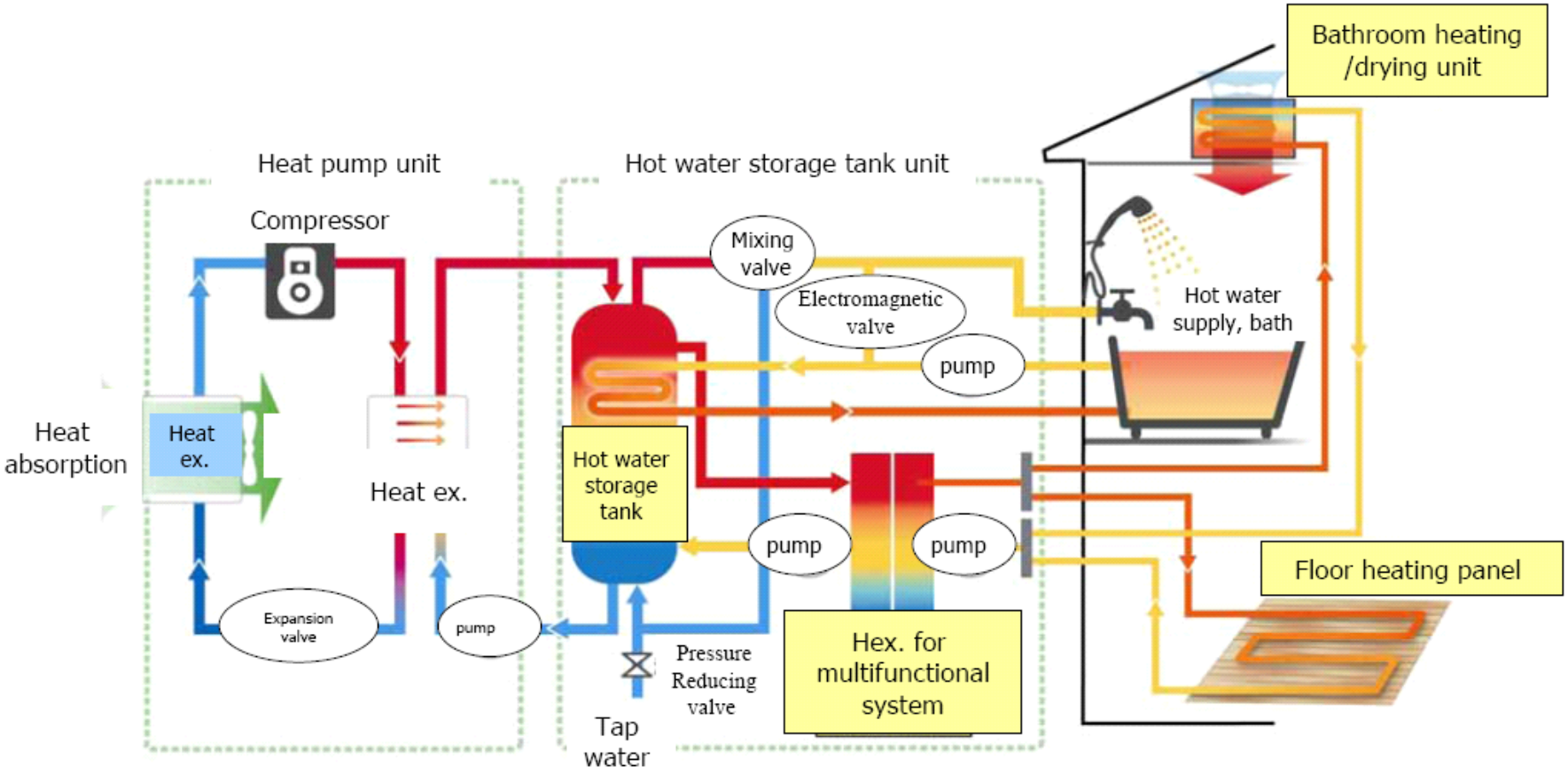

(Stene, 2004)

# Hydronic Heating System + HPWH



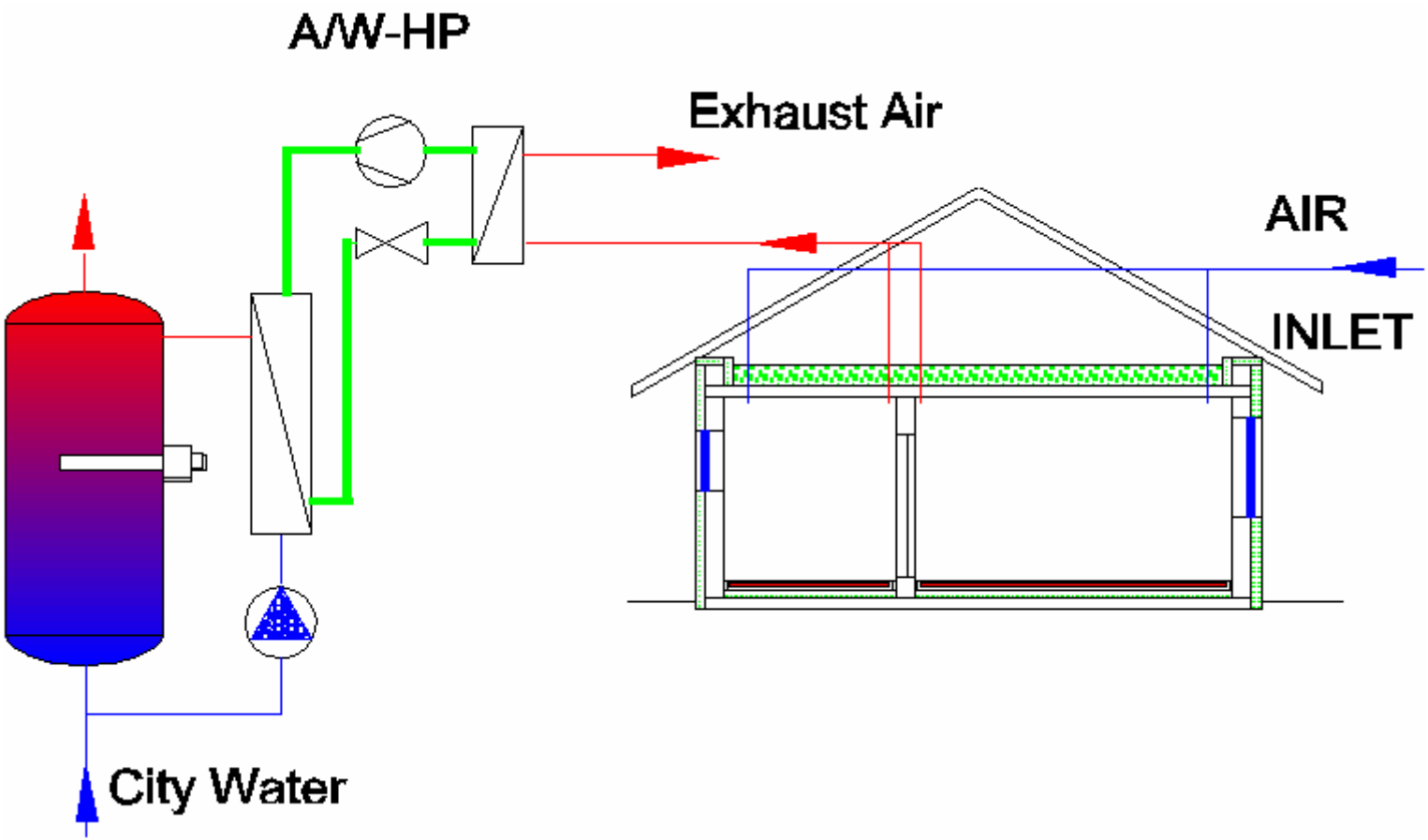

(Stene, 2004)

# HPWH + Hydronic Heating System

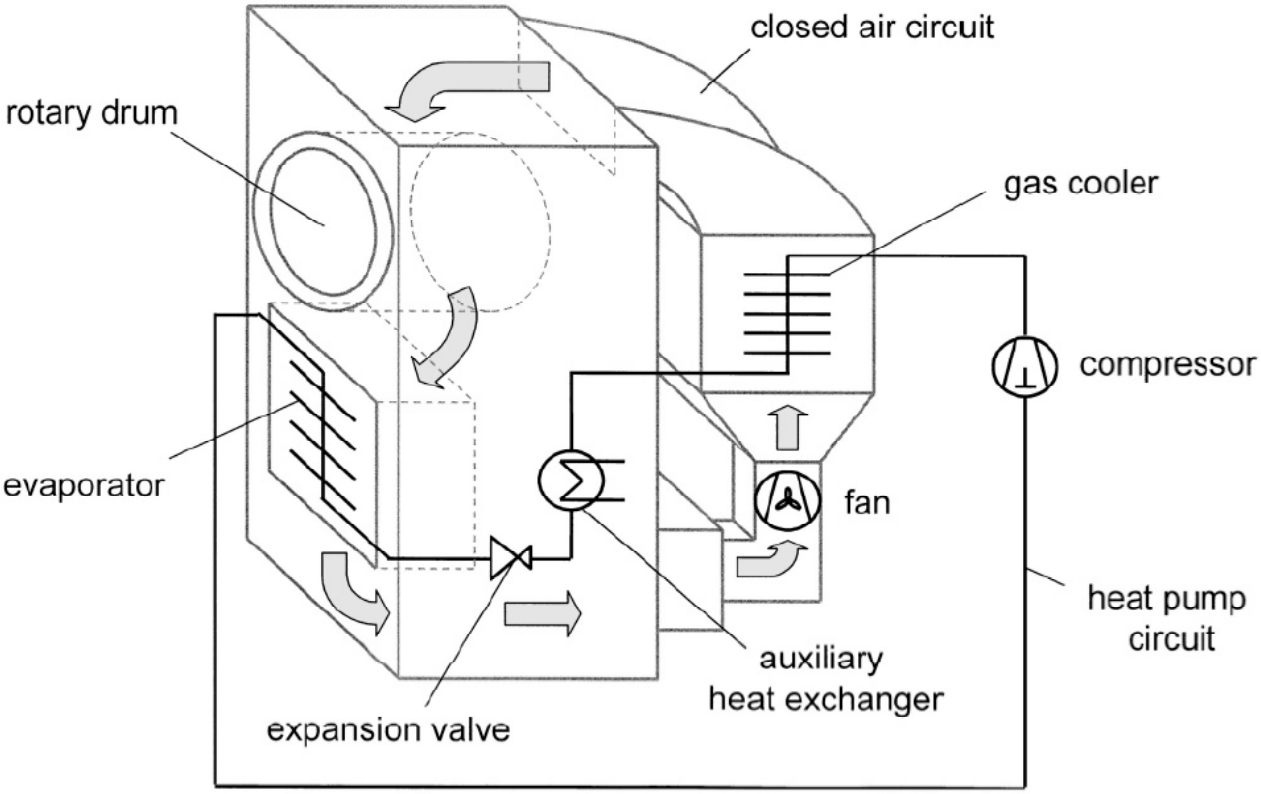


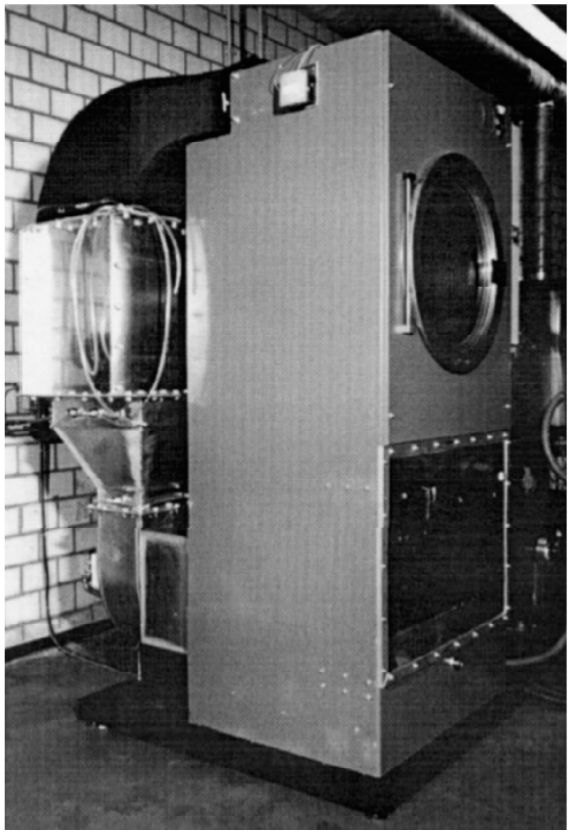

(Hihara, 2004)

# Application – Exhaust Air Heat recovery + HPWH



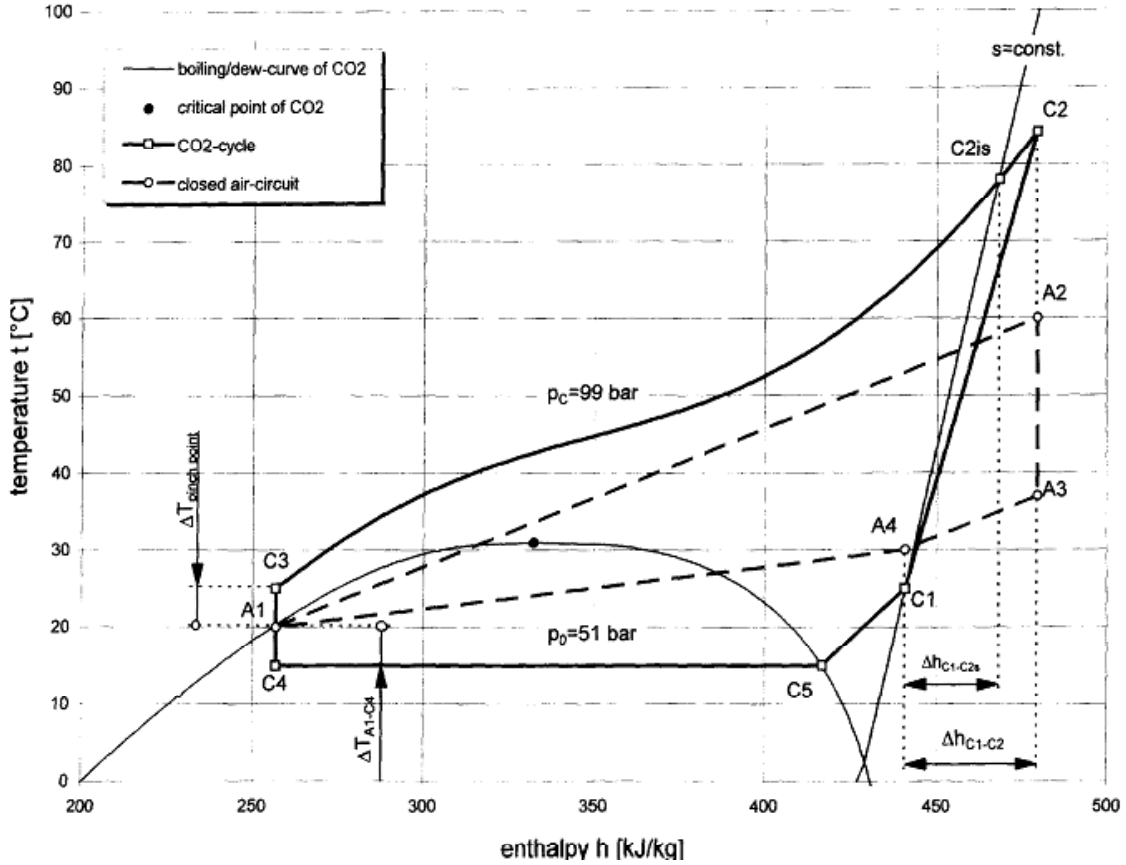
# Application – Laundry Heat Pump Dryer



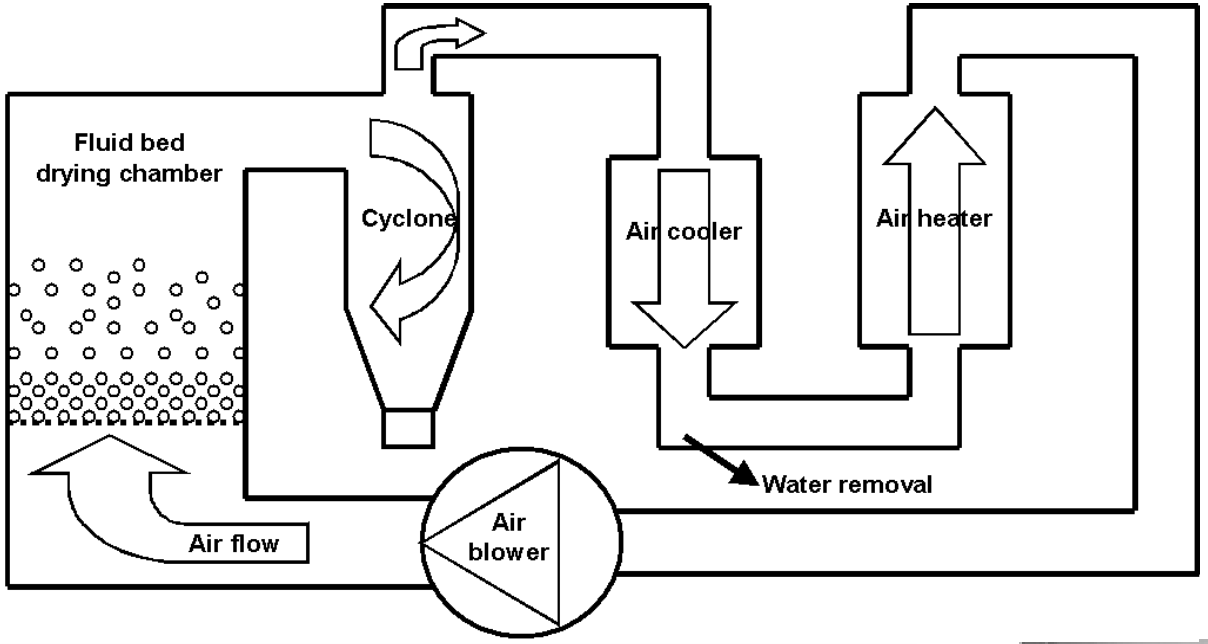
(Klöcker et al., 2001)

# Laundry Heat Pump Dryer

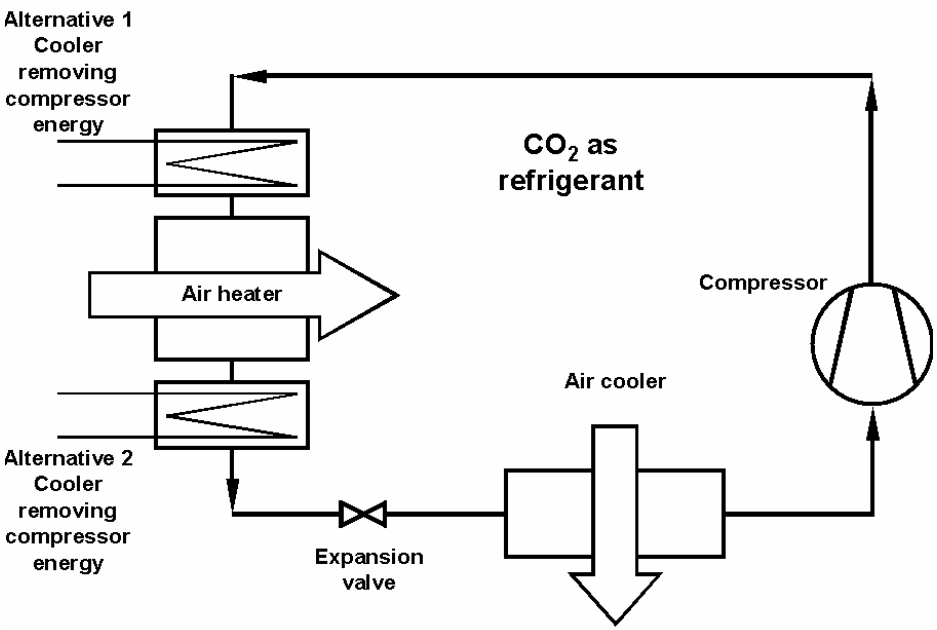



(Schmidt et al., 1998)

# Application – Heat Pump for Food Drying

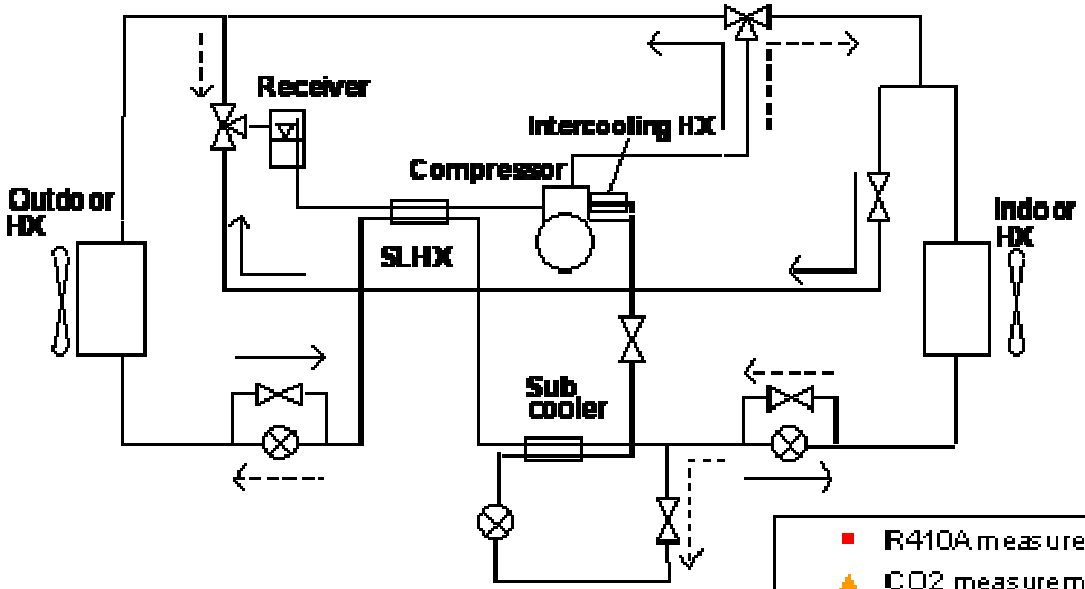



Test rig at SINTEF

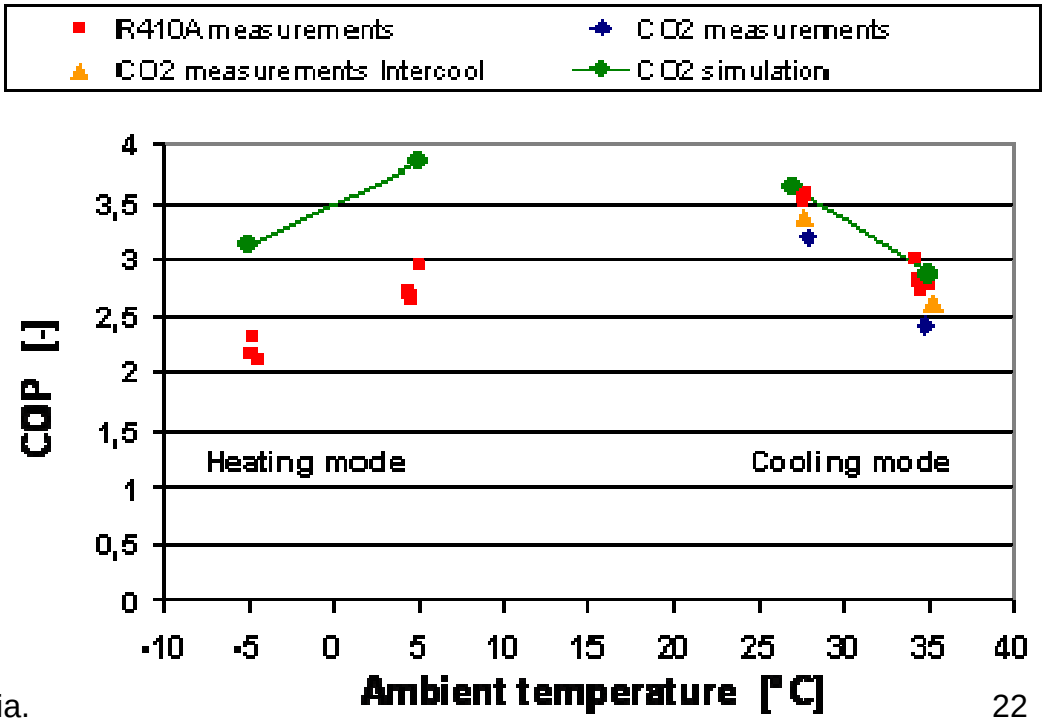




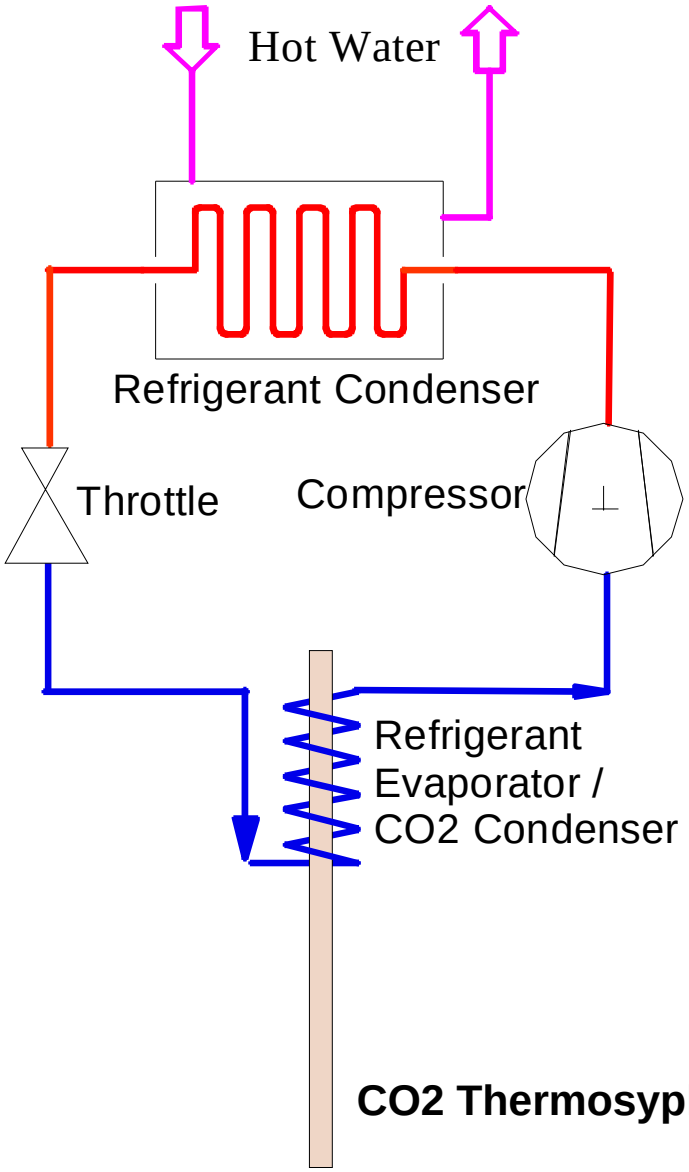

# Application – Residential AC

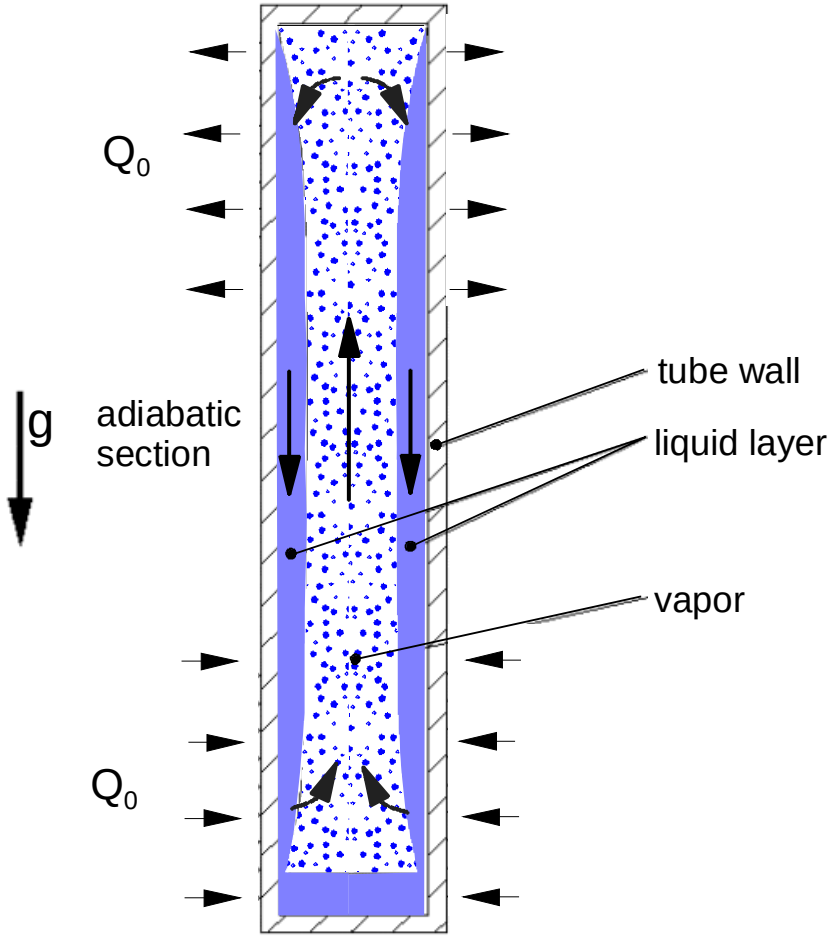



(Jacobsen et al., 2004)

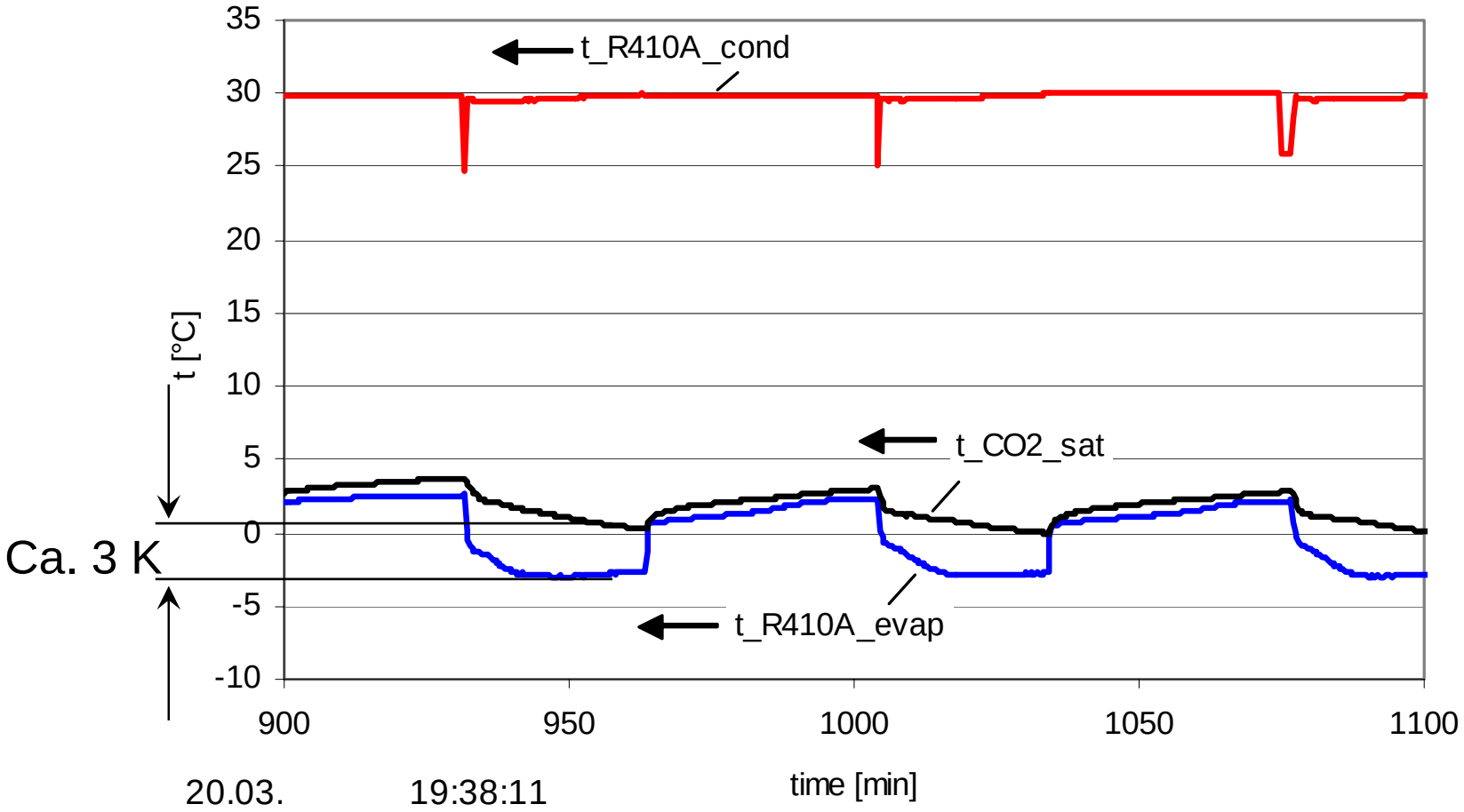


# Application – Two-phase Thermosyphon

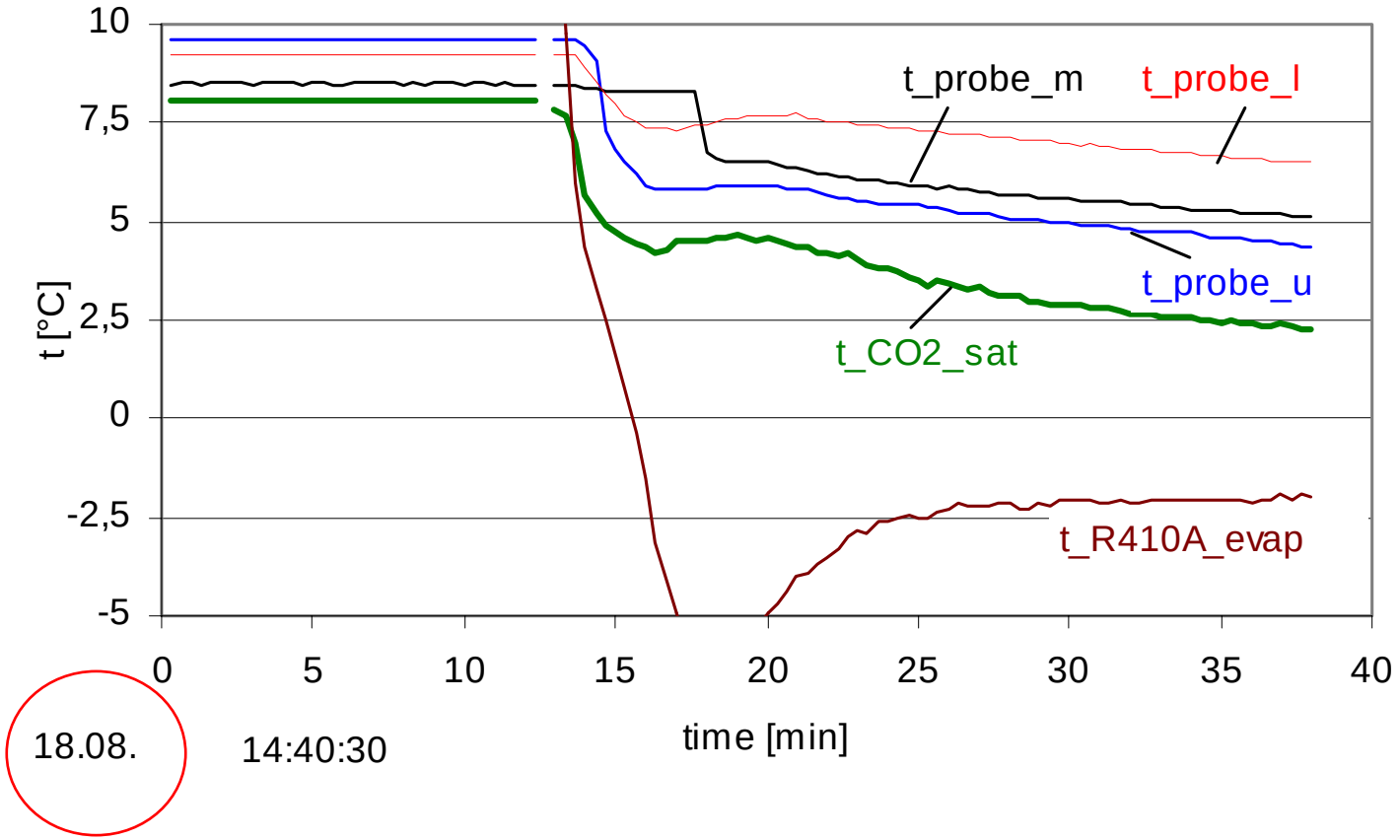


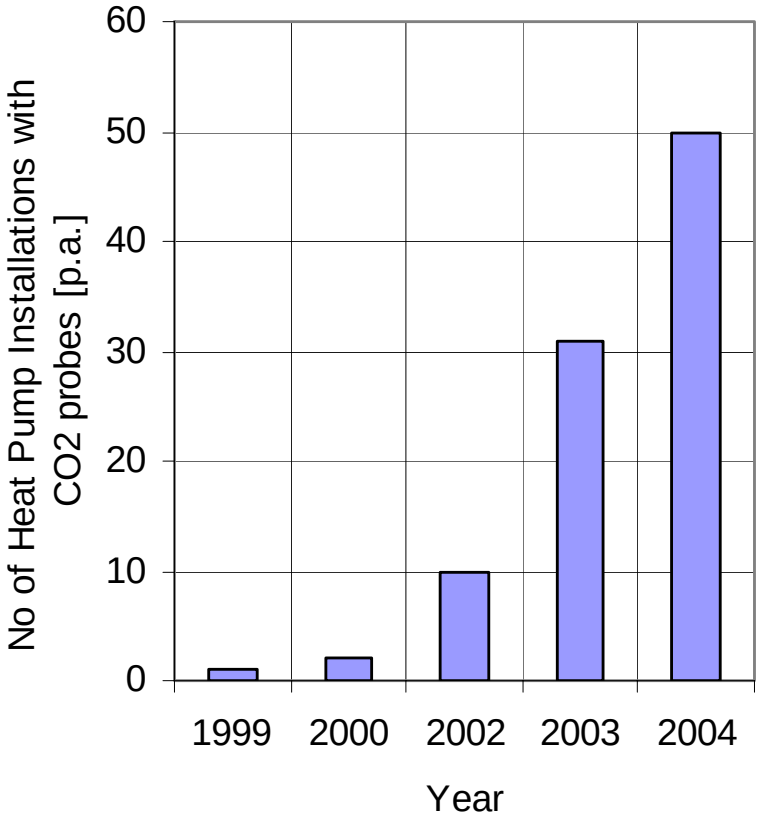
# Measured Temperatures

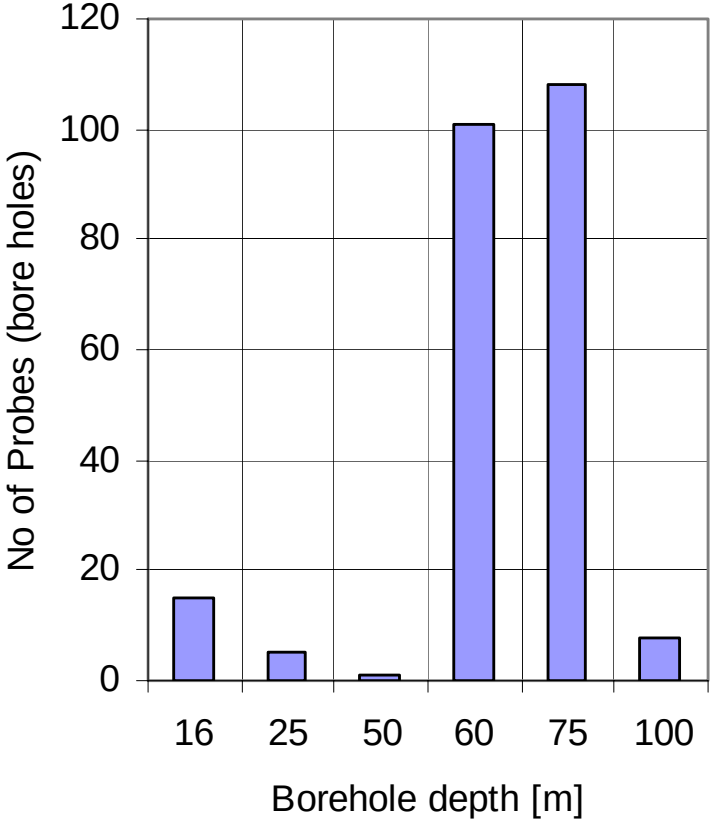


# Start-up of the Natural Circulation



# Market Experience



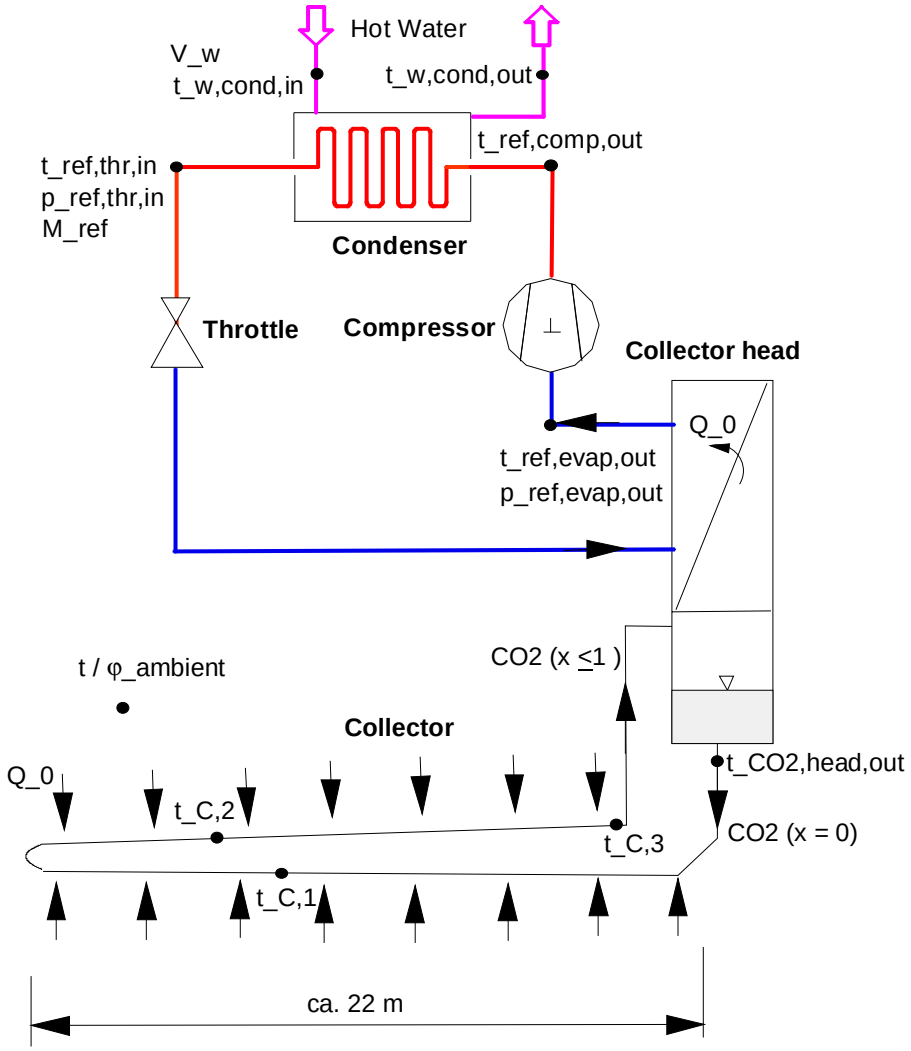




⇨ Natural Circulation: + Energy Efficiency

⇨ CO2 = Environmentally friendly working fluid with advantageous properties (heat transfer, pressure drop)

⇨ Secondary System: + no oil in the ground coil
- $\Delta T$ necessary

# Application – $CO_2$ Collector

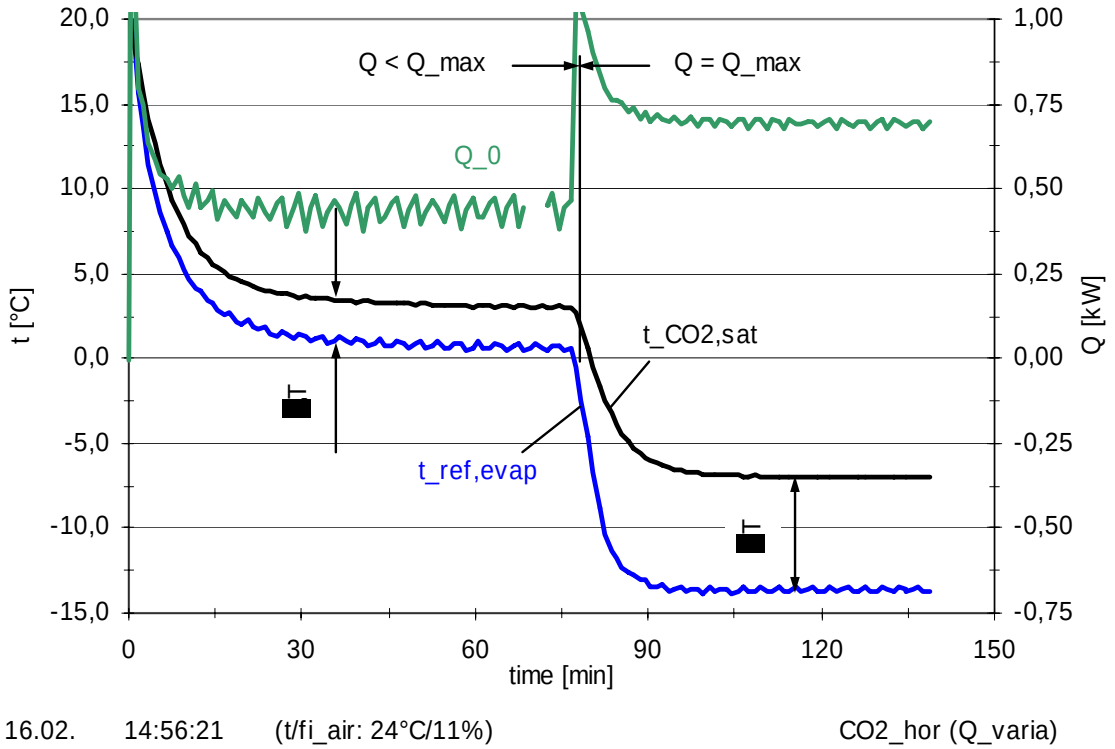



Horizontally installed Ground/$CO_2$-Heat Exchanger:

Design based on thermosyphon principle

Test rig constructed at the Institute of Thermal Engineering for analyzing the suitability of the proposed system

# $CO_2$ Collector - Initial Measurements

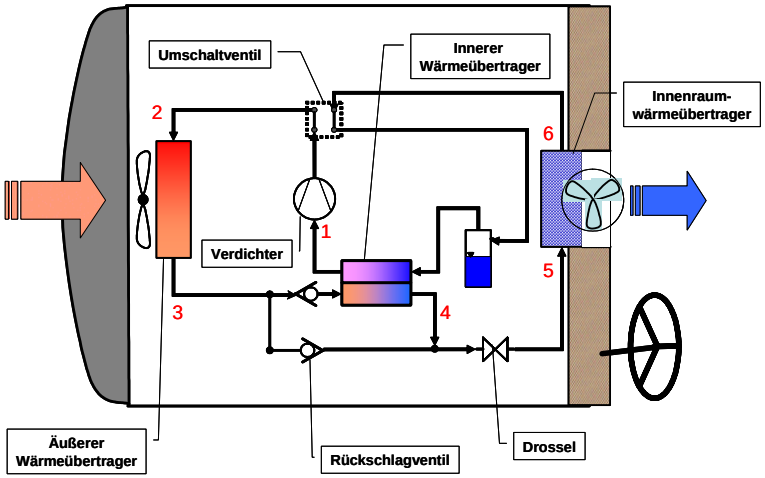



Prelim. Conclusions :

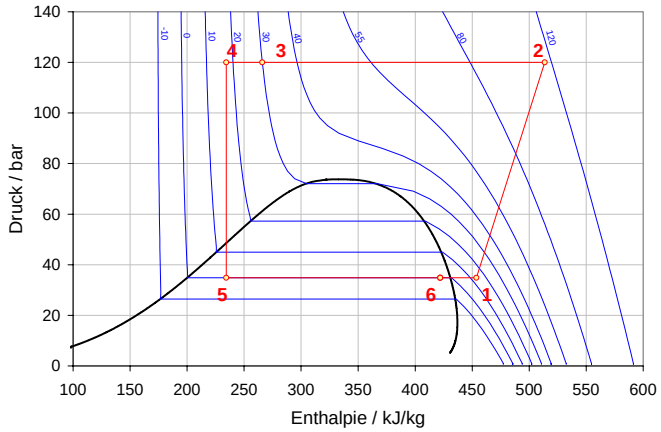
- Natural circulation starts immediately after start-up of the heat pump and offers steady-state operation as well as high evaporation temperature, but
- Required temperature difference between condensing $CO_2$ and evaporating refrigerating depends strongly on capacity

# Further Applications – Automotive AC & HP

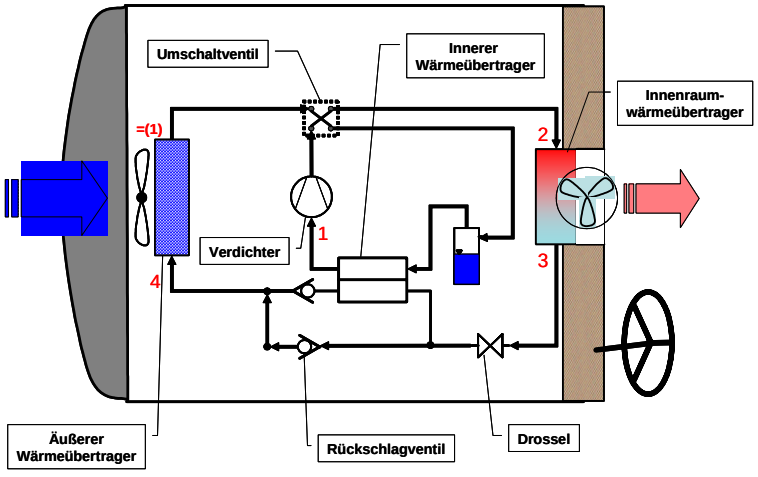
## AC



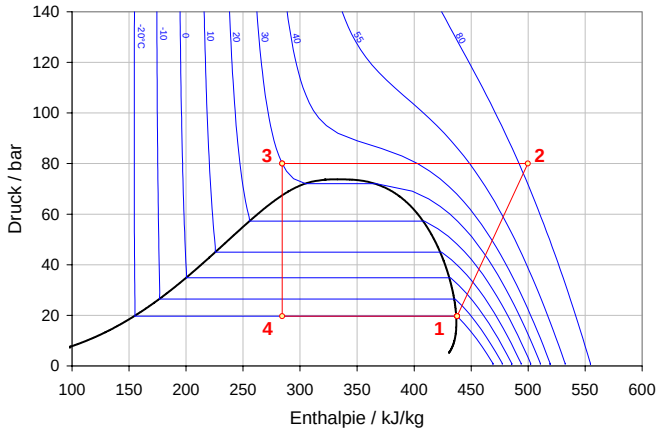

Umgebungstemperatur = 30°C



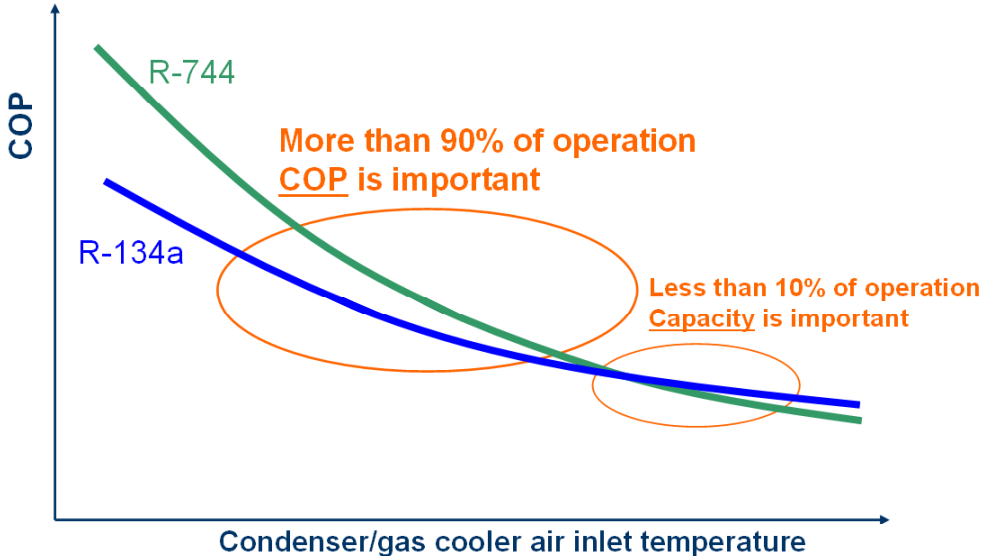

## HP



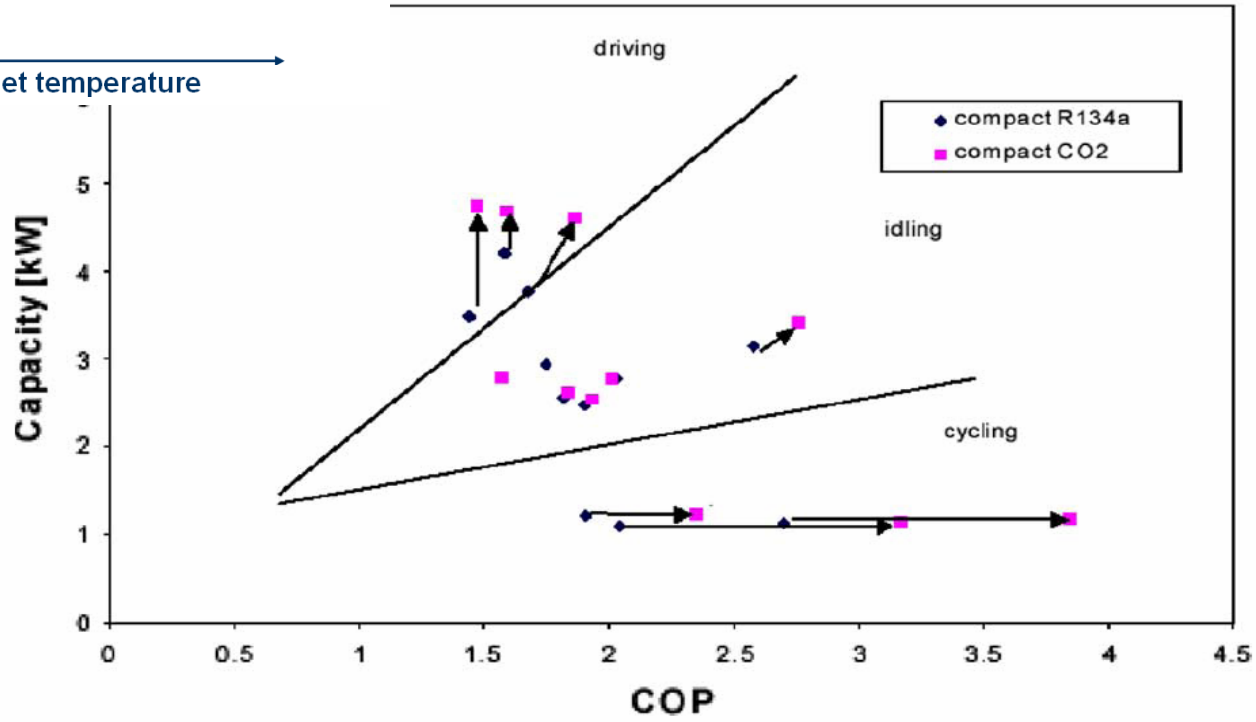

Umgebungstemperatur = -20°C



# Automotive AC

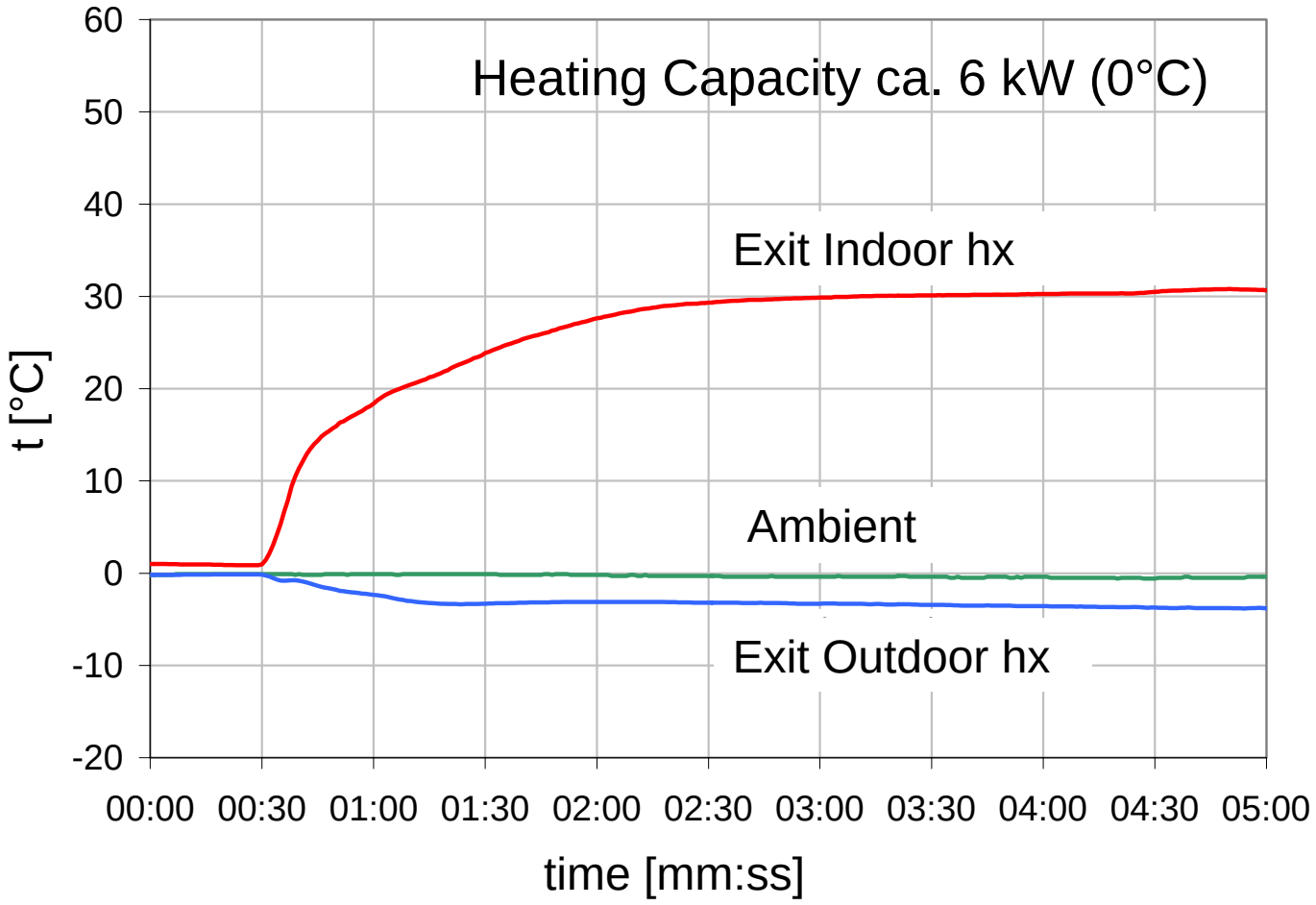



(Nekså, 2004)




(Kim et al., 2004)

# Automotive Air/Air-HP




**IWT**

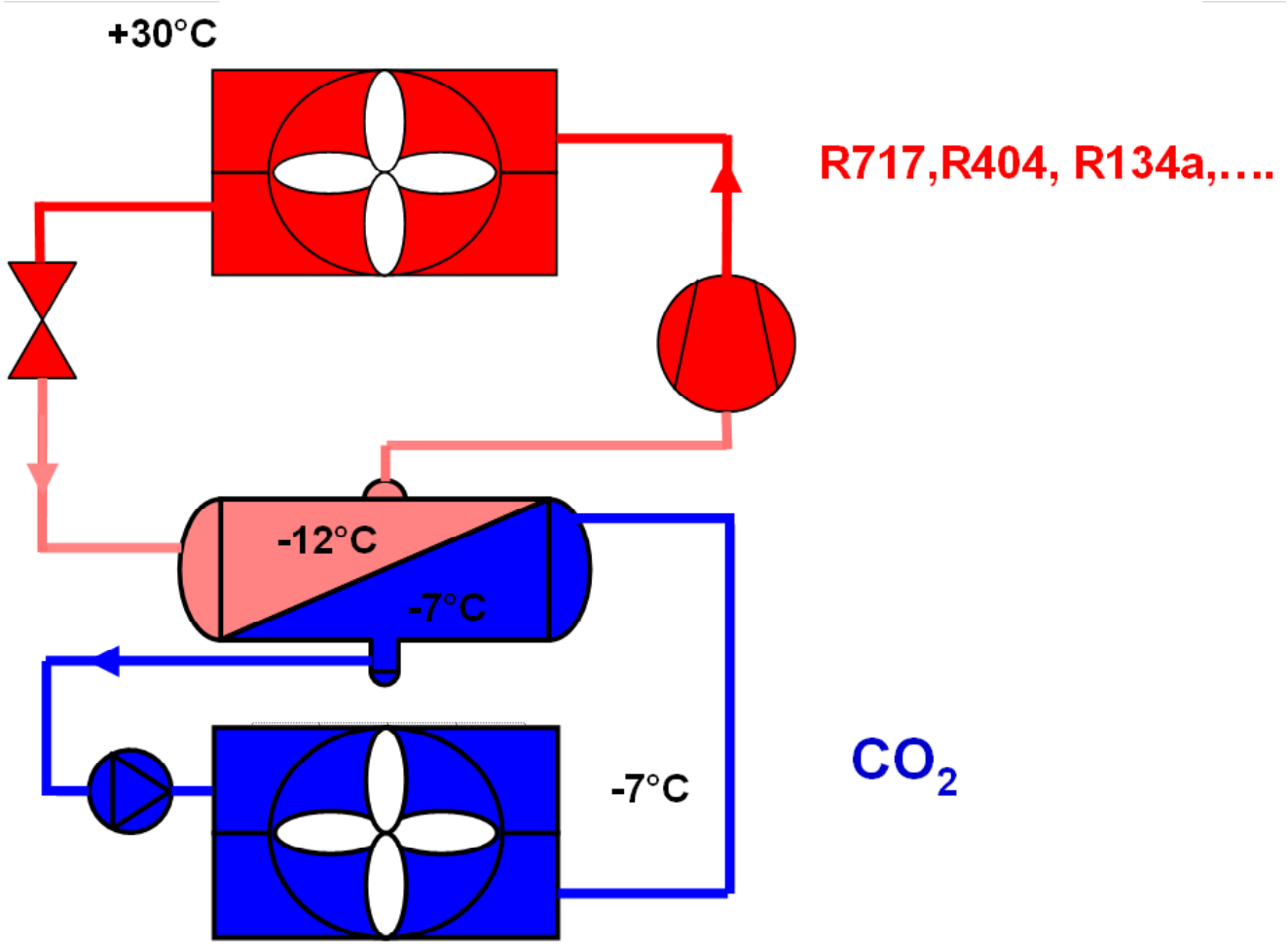
in co-operation with

vif

Kompetenzzentrum –
Das virtuelle Fahrzeug
Forschungsgesellschaft mbH

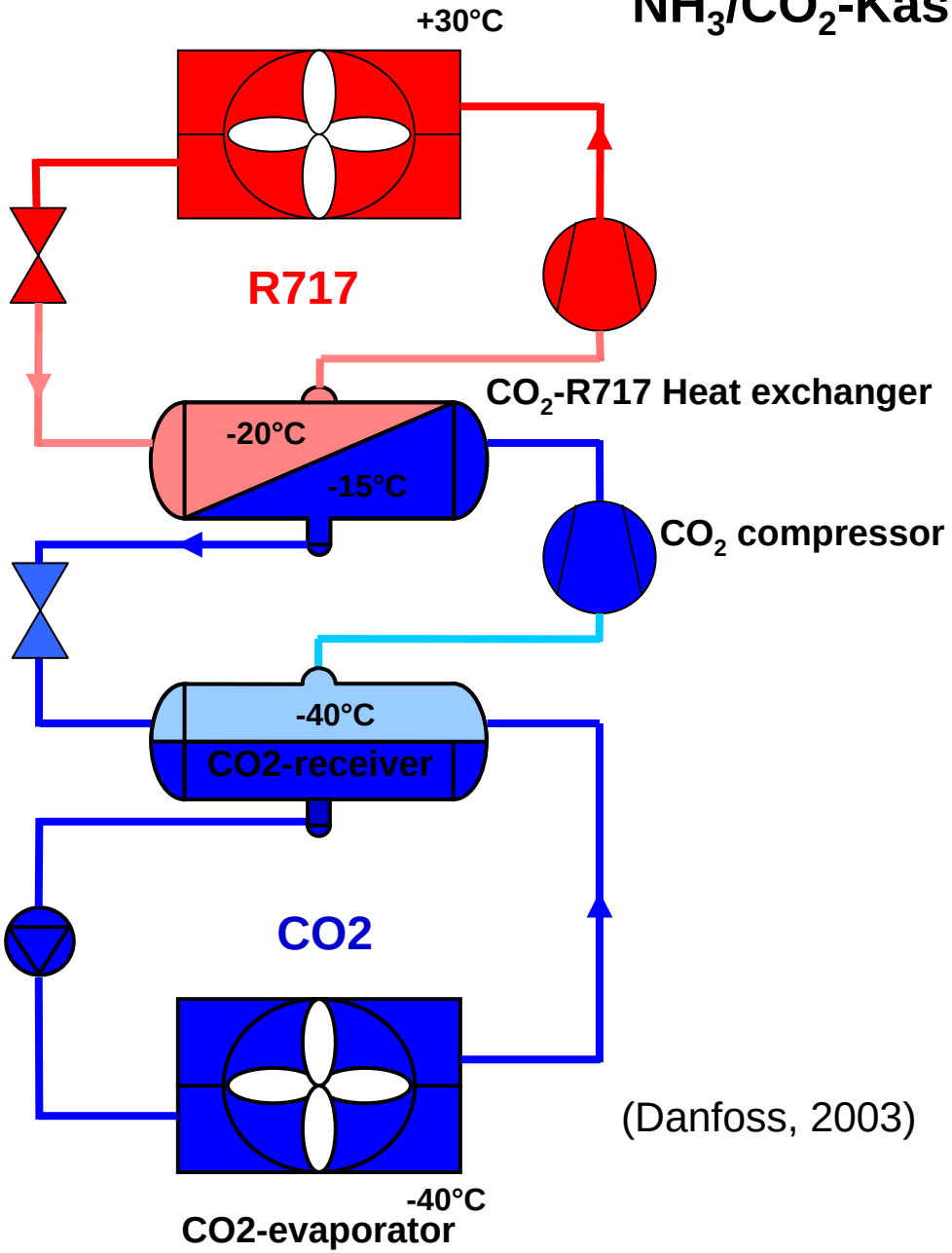
# Further Applications - $NH_3/CO_2$-cascade system

## (e.g supermarket refrigeration)

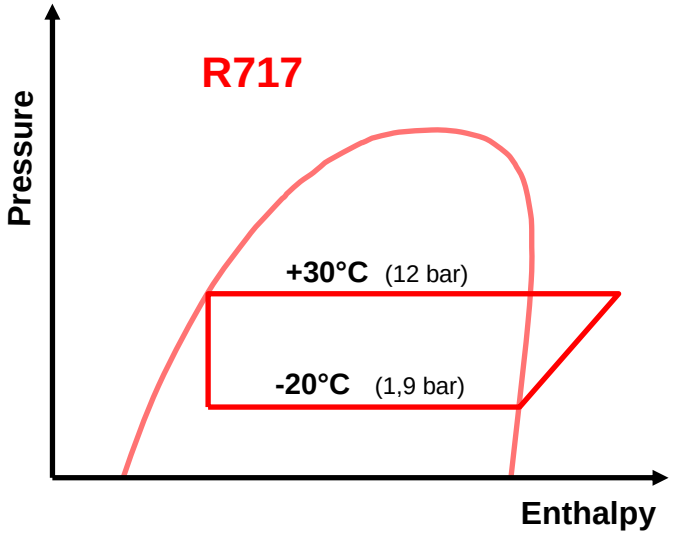


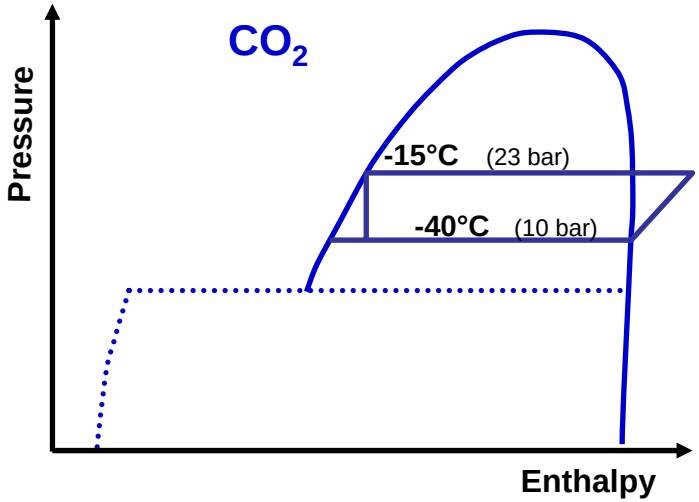

(Danfoss, 2003 - modified)

# $NH_3/CO_2$-Kaskade




(Danfoss, 2003)

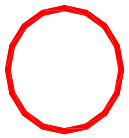
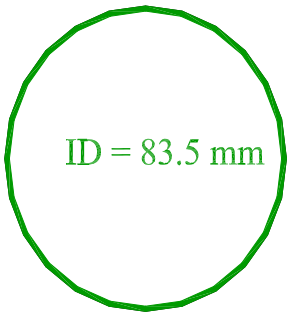
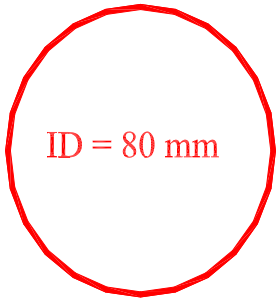
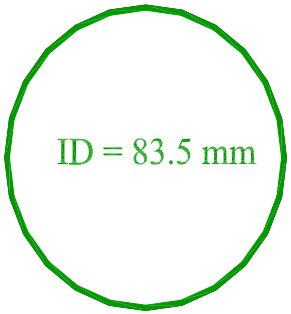
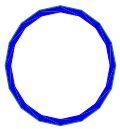


# Components – Tube dimensions for refrigeration application

TUBE DIMENSION FOR $CO_2$ AS THE WORKING FLUID WITH R-404a AND THE BRINE DOWTHERM J.

Capacity 50 kW at - 30 °C air temperature.

| | FLUID | | |
|---|---|---|---|
| | R = 404a | Dow J | $CO_2$ |
| SUPPLY LINE |  ID = 35 mm |  ID = 83.5 mm |  ID = 14.1 mm |
| RETURN LINE |  ID = 80 mm |  ID = 83.5 mm |  ID = 32.3 mm |

# $CO_2$-Components – Automotive AC Compressor



R134a compressor

155 ccm

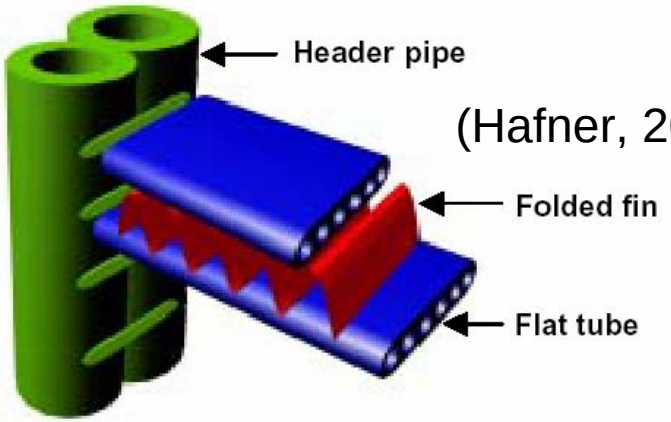


R744 compressor

21 ccm

(Parsch, 2002)

# $CO_2$-Components – Automotive hx




(Hafner, 2002)





**Possibly suited for residential applications as well**

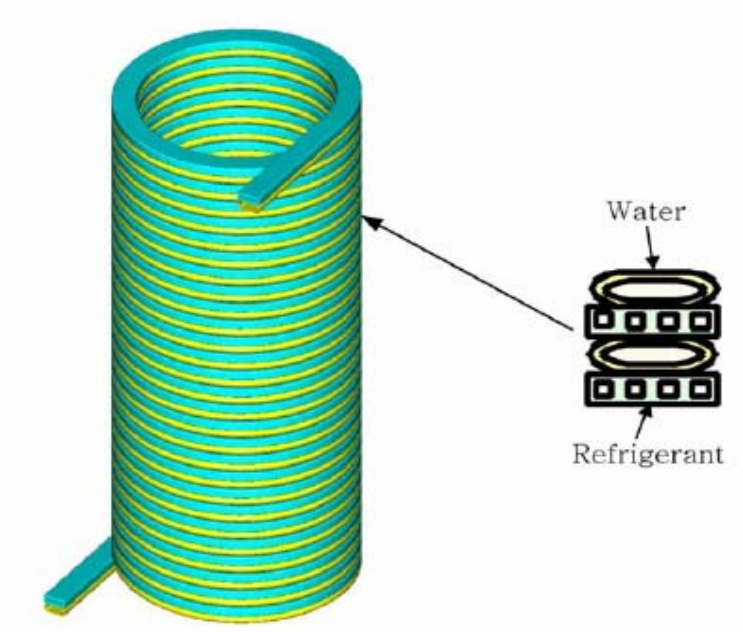
# $CO_2$-Components – Tube in Tube (IHX or GC)

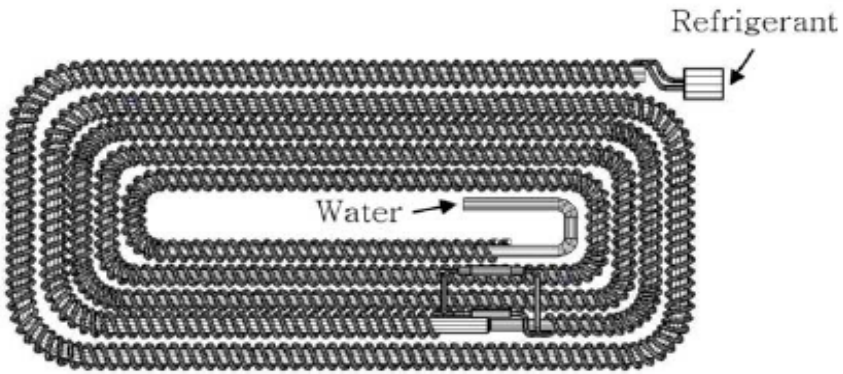







# $CO_2$-Components – Examples for HPWH-Gas Cooler




(Pettersen, 2000)

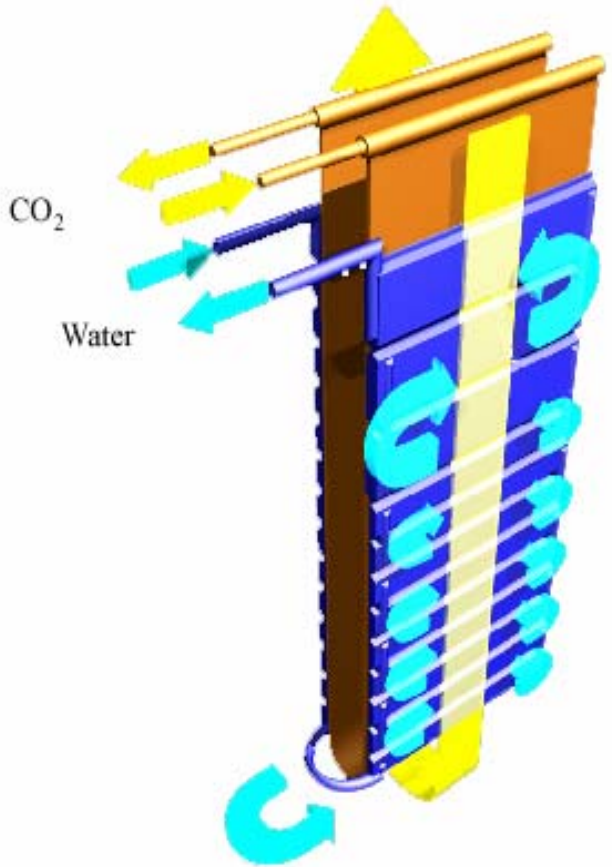



Fig.3 The Developed $CO_2$ - Water Heat Exchanger

(Denso)

# Summary and Outlook

- Properties: Low critical temperature – Operation close to the critical point
- $CO_2$ Heat Pumps: HPWH most promising, further under development
- Further Applications: Automotive AC/HP, cascade systems, vending machine, …
- Activities in Austria
  - Heat Pump Water Heater: test rig & product development
  - Waste Heat Recovery from exhaust air
  - Thermosyphon: vertical on the market; horizontal under development
  - Automotive AC
  - Secondary Loop Systems (super market, ice rink)
- Legal situation in Austria ?

# Thank you for your attention!