CO_2 Systems for Supermarket Applications

Dr. Ángel Álvarez Pardiñas
Postdoctoral Researcher at Department of Energy and Process Engineering
Norwegian University of Science and Technology NTNU
angel.a.pardinas@ntnu.no

Outline

- Introduction
- Transcritical CO_2 systems for supermarkets
- Booster system
- Developments for warm/hot climates
  - Parallel compression
  - Ejectors
  - Others: mechanical subcooling, expanders, etc.
- Flooded evaporators
- Integration of demands

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1st generation (1830-1930) Work

2nd generation (1930-1990) Safety

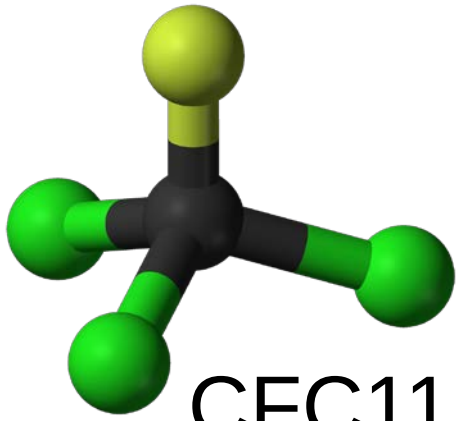
3rd generation (1990-2010) Ozone protection

4th generation (2010-…) Global warming

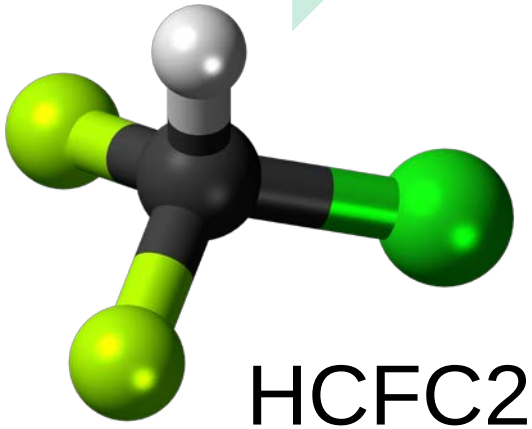
*125 years of Linde. A chronicle

*Advertisement in ICE and REFRIGERATION, 1922, vol. 63

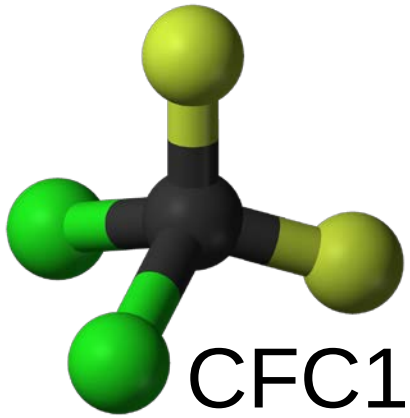
1st generation	2nd generation	3rd generation	4th generation
(1830-1930)	(1930-1990)	(1990-2010)	(2010-…)
Work	Safety	Ozone protection	Global warming



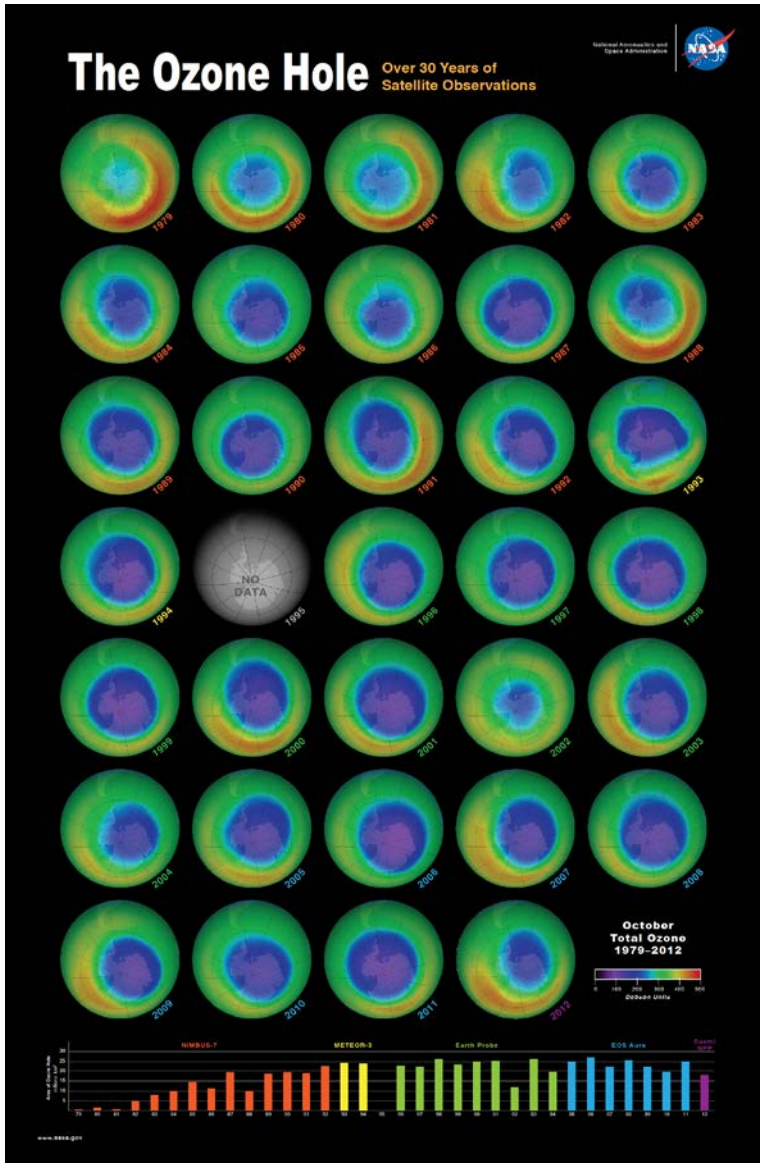
CFC11



HCFC22



CFC12



*NASA. Total Ozone (1979 – 2012)

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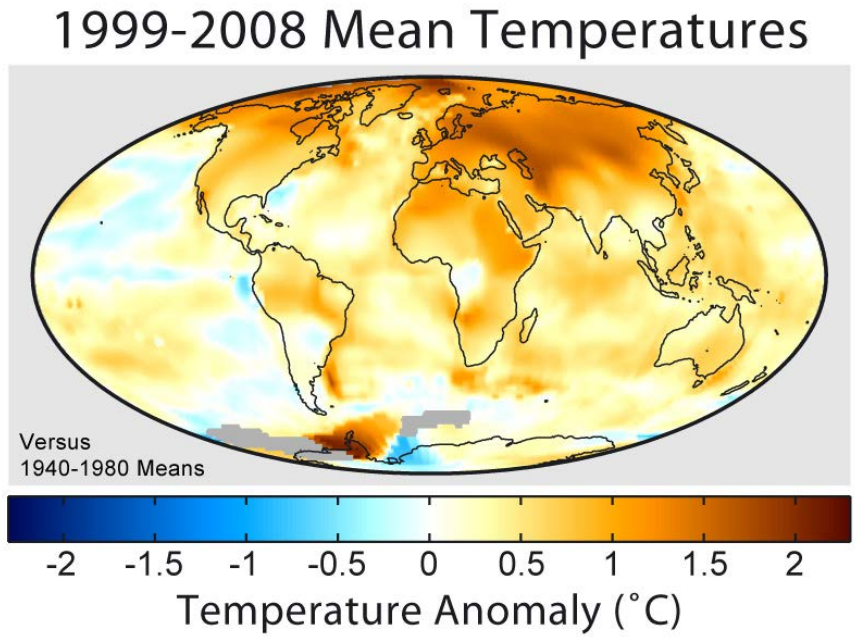


1987

MONTREAL PROTOCOL

caring for all life under the sun

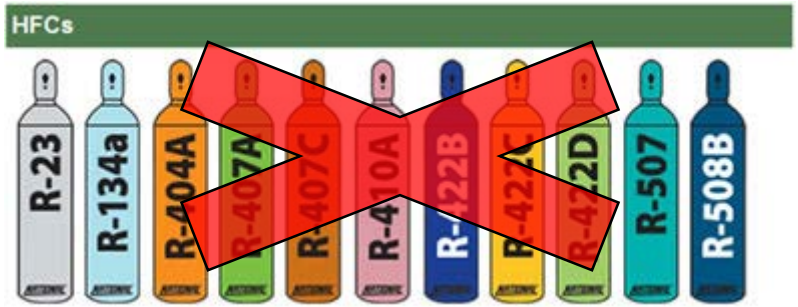
*www.mopia.ca

*www.refrigeranthq.com

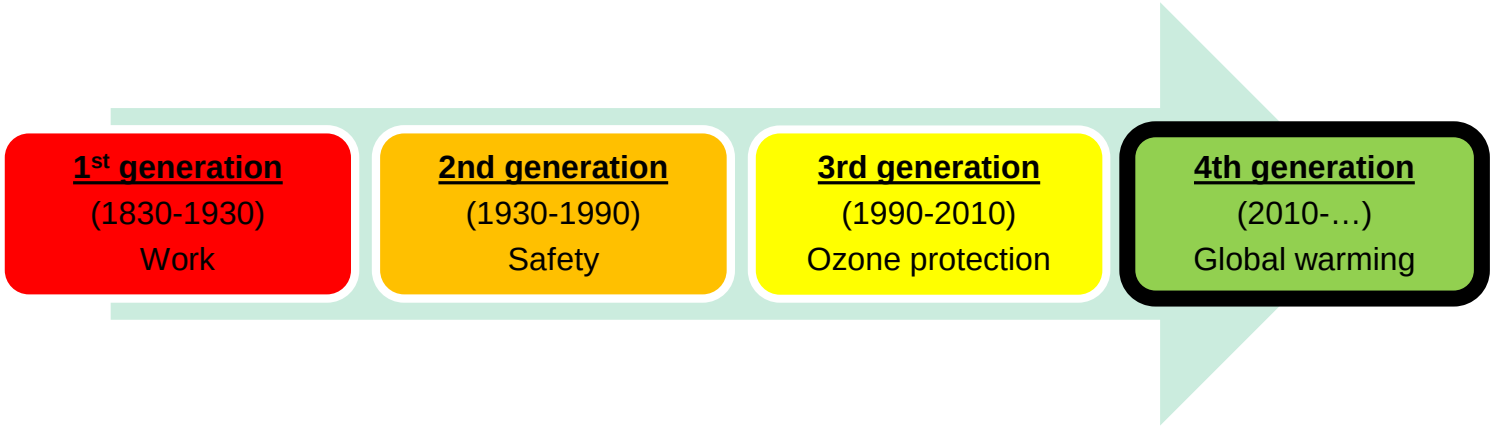
1st generation	2nd generation	3rd generation	4th generation
(1830-1930)	(1930-1990)	(1990-2010)	(2010-…)
Work	Safety	Ozone protection	Global warming

Kyoto Protocol (1997) & Amendments

EUs original (2006) and new (2014) F-gas regulation



**www.refrigeranthq.com*



Kyoto Protocol (1997) & Amendments

EUs original (2006) and new (2014) F-gas regulation

~~**HFOs (R1234yf, R1234ze, etc.)**~~

http://www.r744.com/articles/8395/germany_warns_r1234yf_could_cause_harm_to_drinking_water

Natural (CO_2, NH_3, HCs)

1995 Prof. Gustav Lorentzen said:

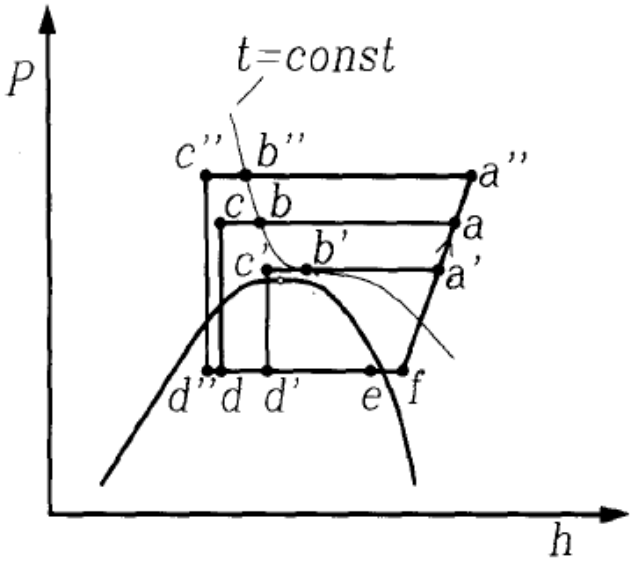
We have heard a great deal lately of the harmful effects to the environment when halocarbon refrigerants are lost to the atmosphere. This should not really have come as a surprise since similar problems have happened over and over again. Numerous cases are on record where new chemicals, believed to be a benefit to man, have turned out to be environmentally unacceptable, sometimes even in quite small quantities (DDT, PCB, Pbetc.).

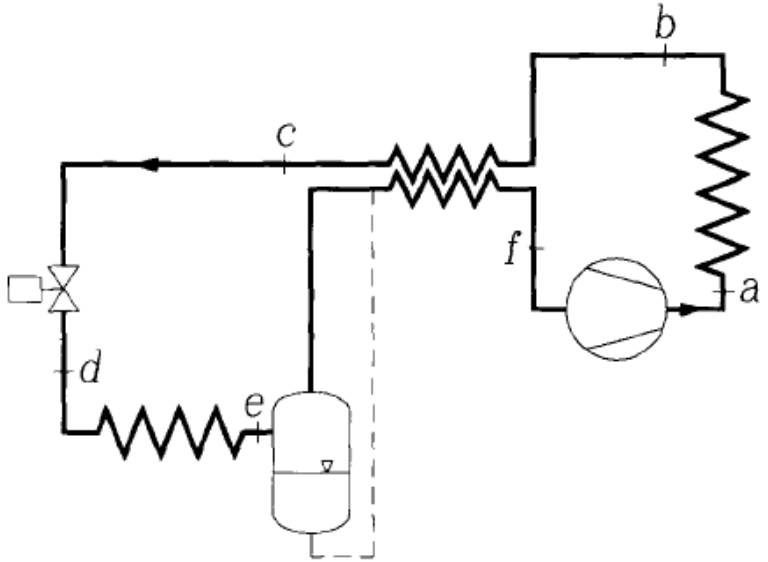
In the present situation, when the CFCs and in a little longer perspective the HCFCs are being banned by international agreement, **it does not seem very logical to try to replace them by another family of related halocarbons, the HFCs, equally foreign to nature.**

Int. J. of Refrigeration 9. Vol. 18, No. 3, pp 190 197, 1995

The revival of CO_2 refrigeration technology

1988. First patent on transcritical CO_2 system





Applications CO_2 transcritical systems

MAC (1989 – 1991)

HEAT PUMP WATER HEATER
EcoCute (2001)
Japan
0.5 Million units/year
5 Million units by 2016

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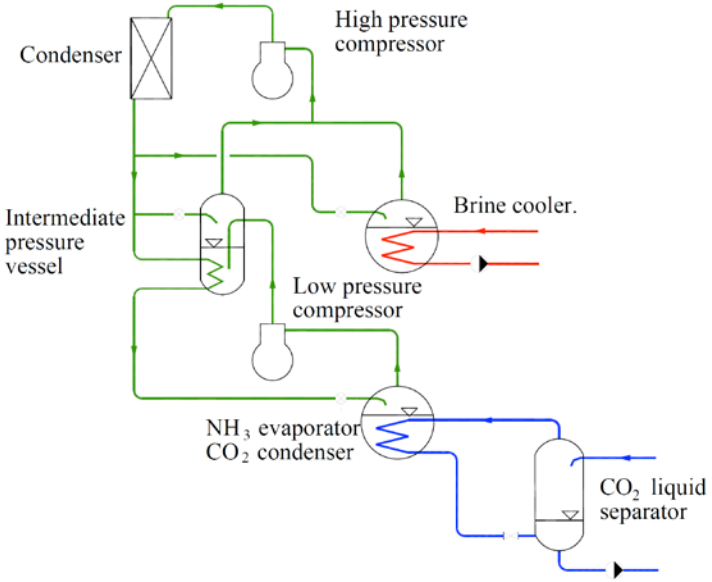
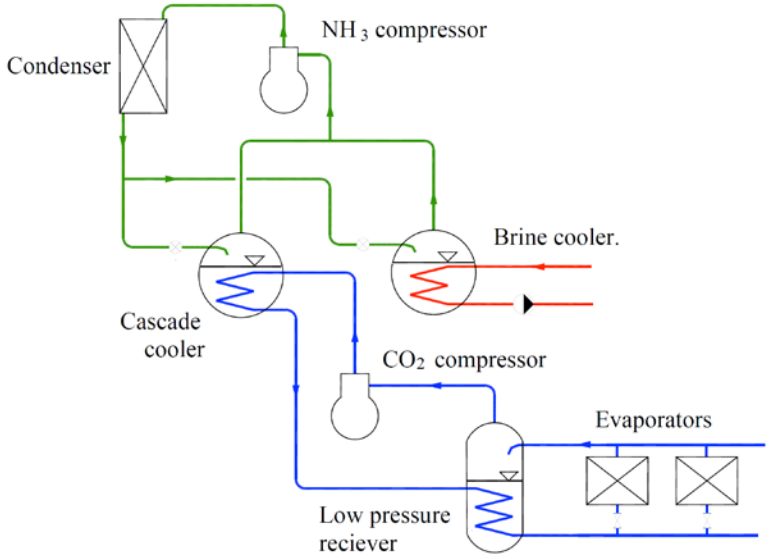
- Flooded evaporators
- Integration of demands
- Cold storage

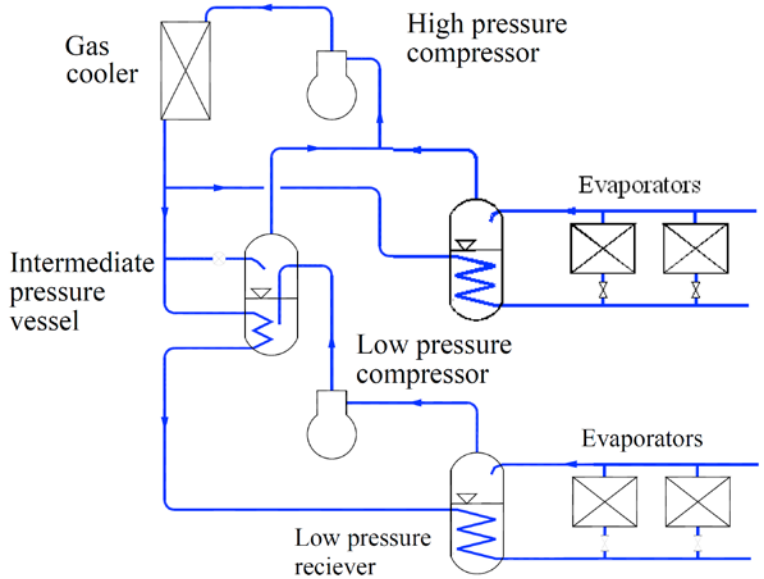
Transcritical CO_2 systems for supermarkets



CO_2 secondary fluid
Rolfsmann, Sweden, 1995



NH_3/CO_2 cascade
Bakken, Norway, 1993



All CO_2, Generation 0

**Slide modified from KEYNOTE LECTURE 2 by Hafner and Nekså at 13th IIR Gustav Lorentzen Conference, Valencia, 2018*

Transcritical CO_2 systems for supermarkets

- All-in-one transcritical CO_2 systems. Preferred option in mild/cold climates.
  - Efficient systems
  - Integrate demands
    - Refrigeration
    - Heating and DHW production
    - Snow melting
    - AC??

- Challenge warm climates
  - Compensate elevated expansion losses

http://r744.com/articles/8384/india_s_first_co2_transcritical_system

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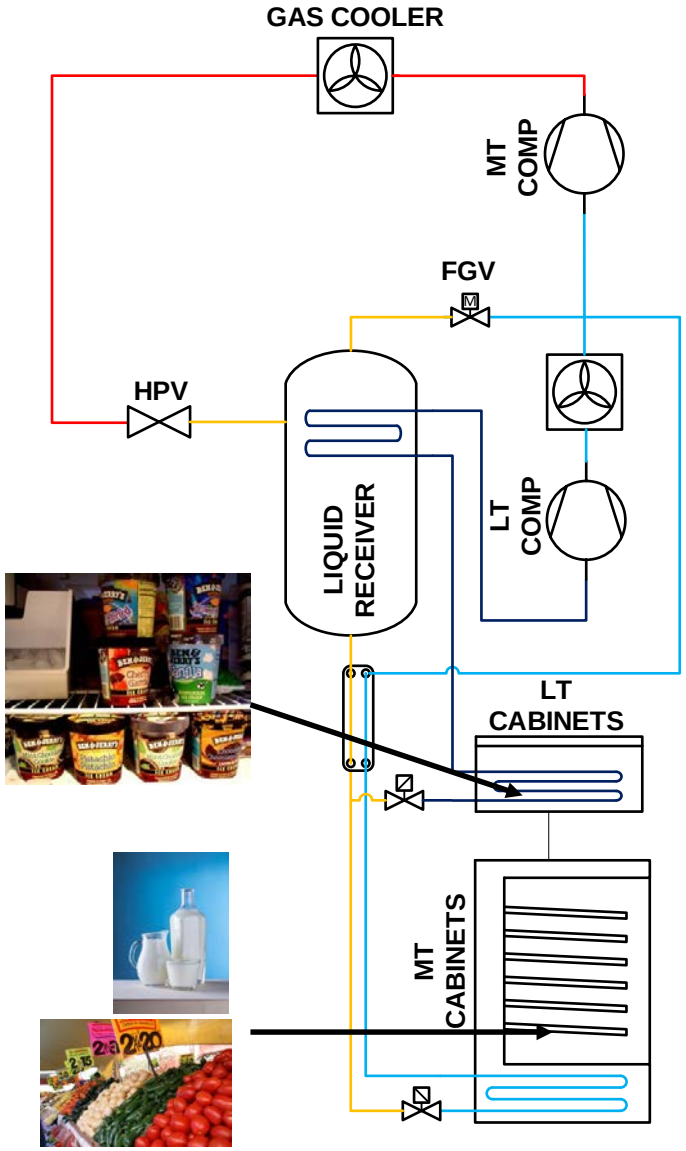
Booster system

- Basic configuration
- First unit in 2004 Switzerland
- Pressure liquid receiver with FGV
- $\uparrow T_{amb} \rightarrow \uparrow$Vapor in liquid receiver
  - Not efficient

Nomenclature
HPV: High pressure valve
FGV: Flash gas valve



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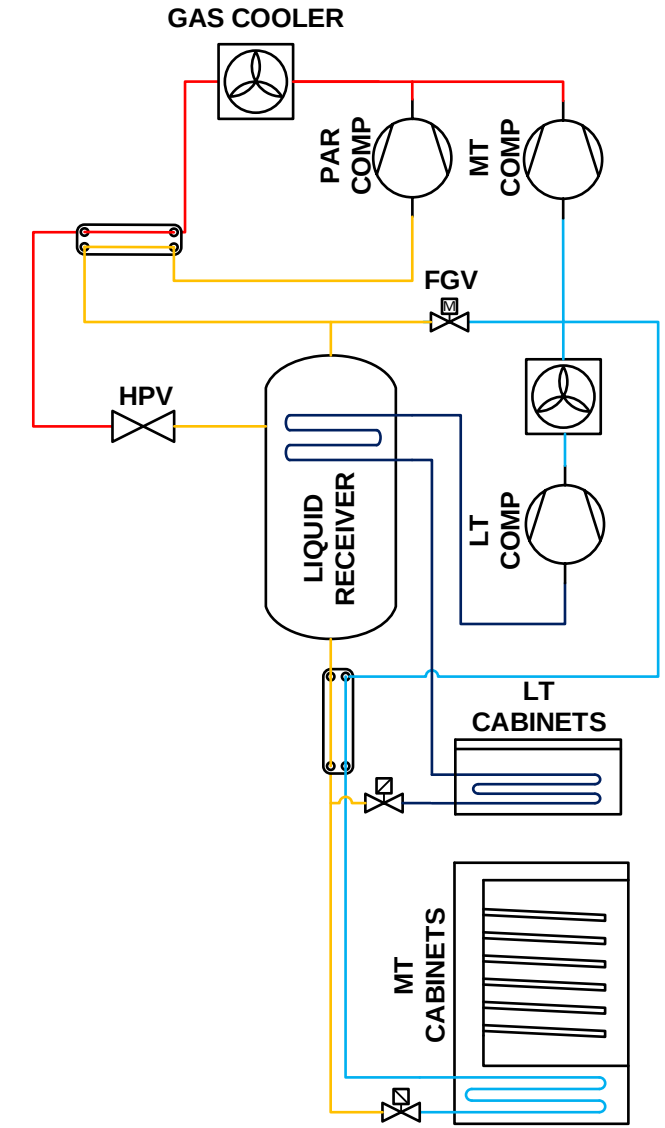
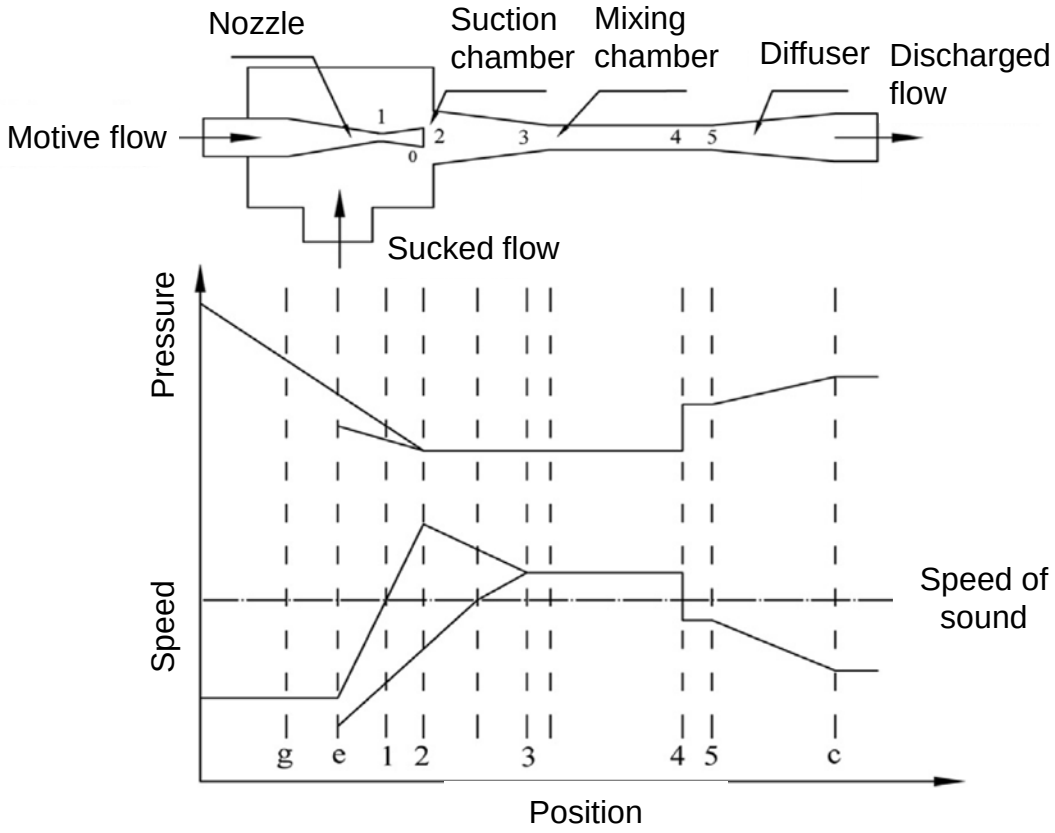
Parallel compression

Nomenclature
HPV: High pressure valve
FGV: Flash gas valve

- Basic configuration in warm climates
- First unit in 2008 Switzerland
- Pressure liquid receiver with parallel compressors
- Power consumption of the pack reduced

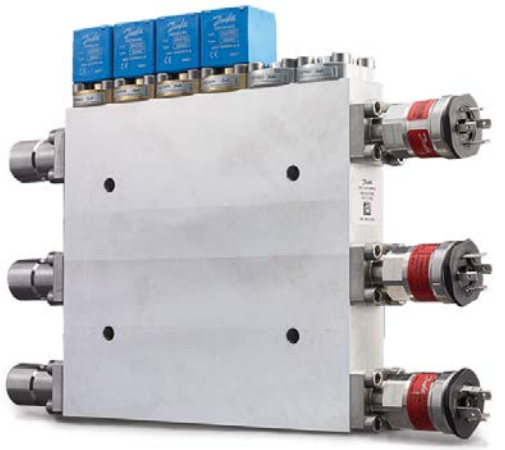


Ejectors



Modified from Chen et al. (2015)

Carel ejector (www.carel.es)

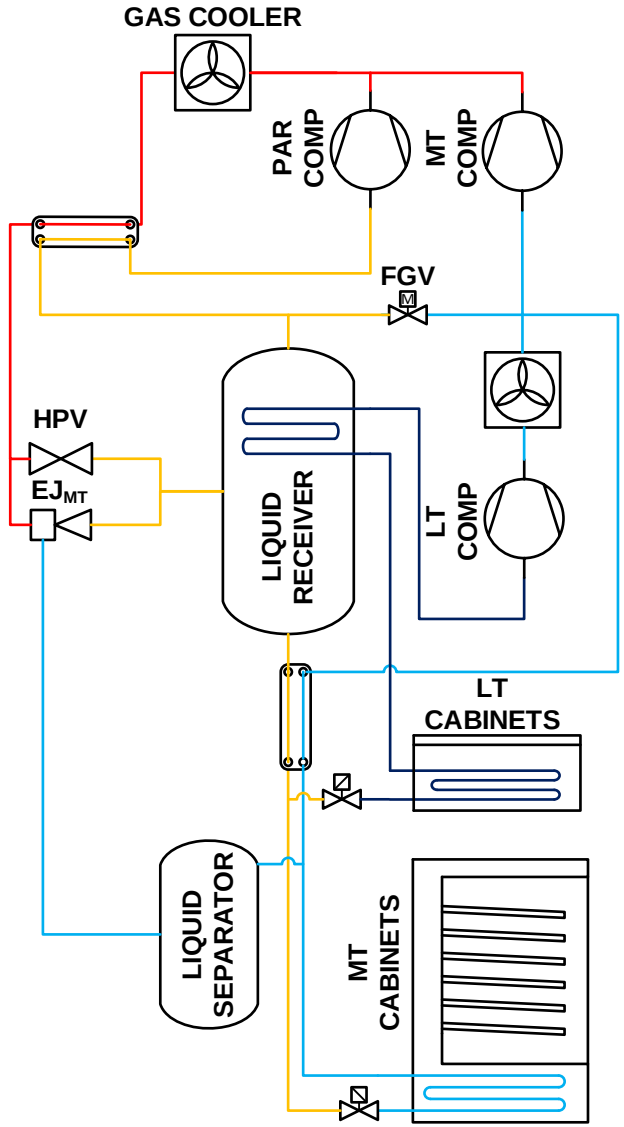


Danfoss multiejector (ACHR News)

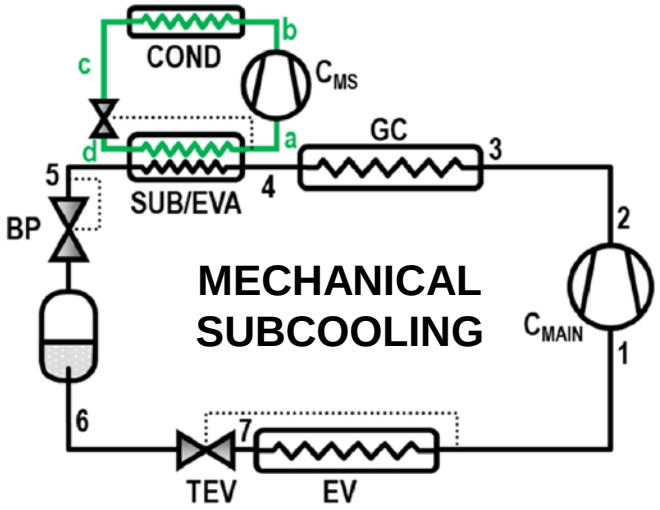
Ejectors

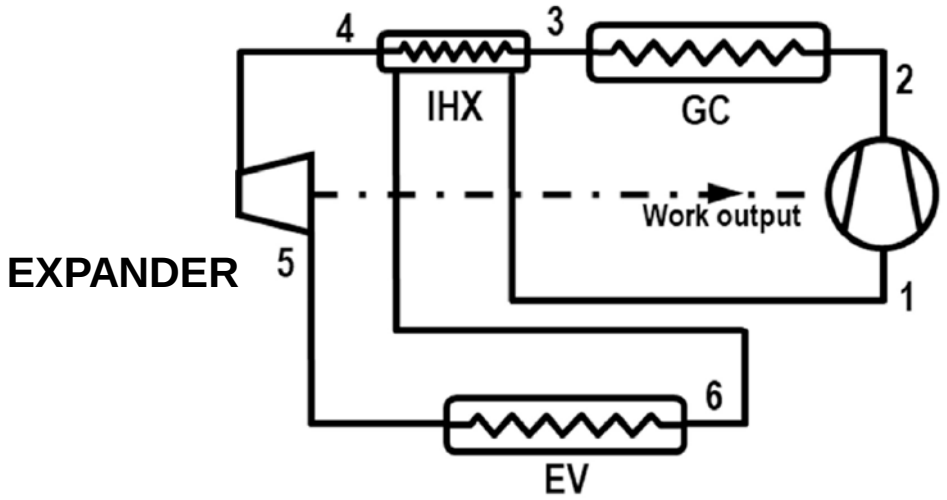
- Control the high pressure
- First unit in 2014 Switzerland
- Recover part of the expansion work available
  - Unload MT compressors, load parallel compressors
- Vapor or liquid ejectors

Nomenclature
HPV: High pressure valve
FGV: Flash gas valve
EJ: Ejector

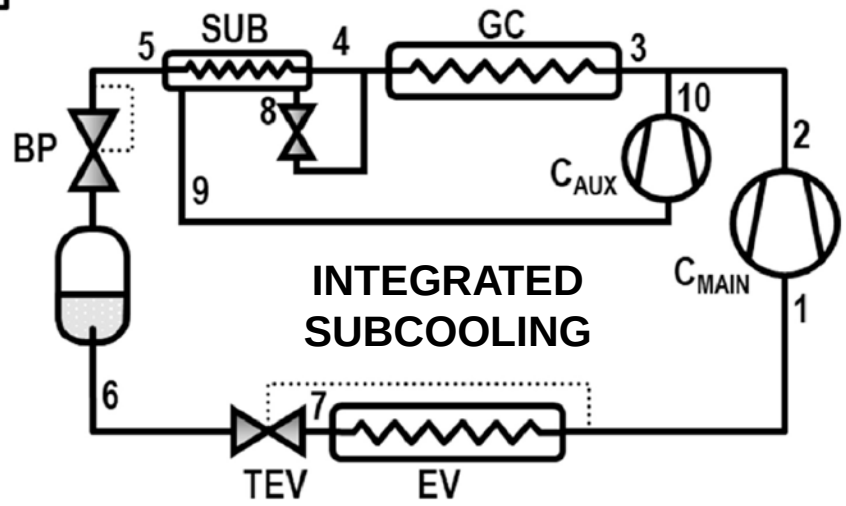


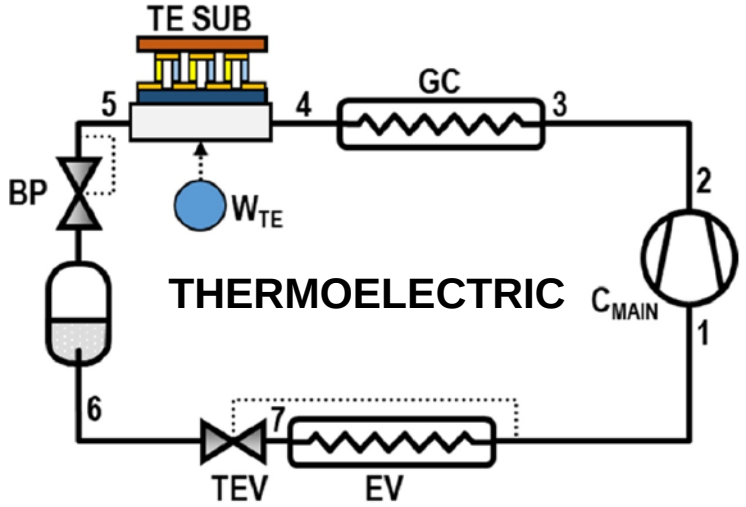
Other solutions





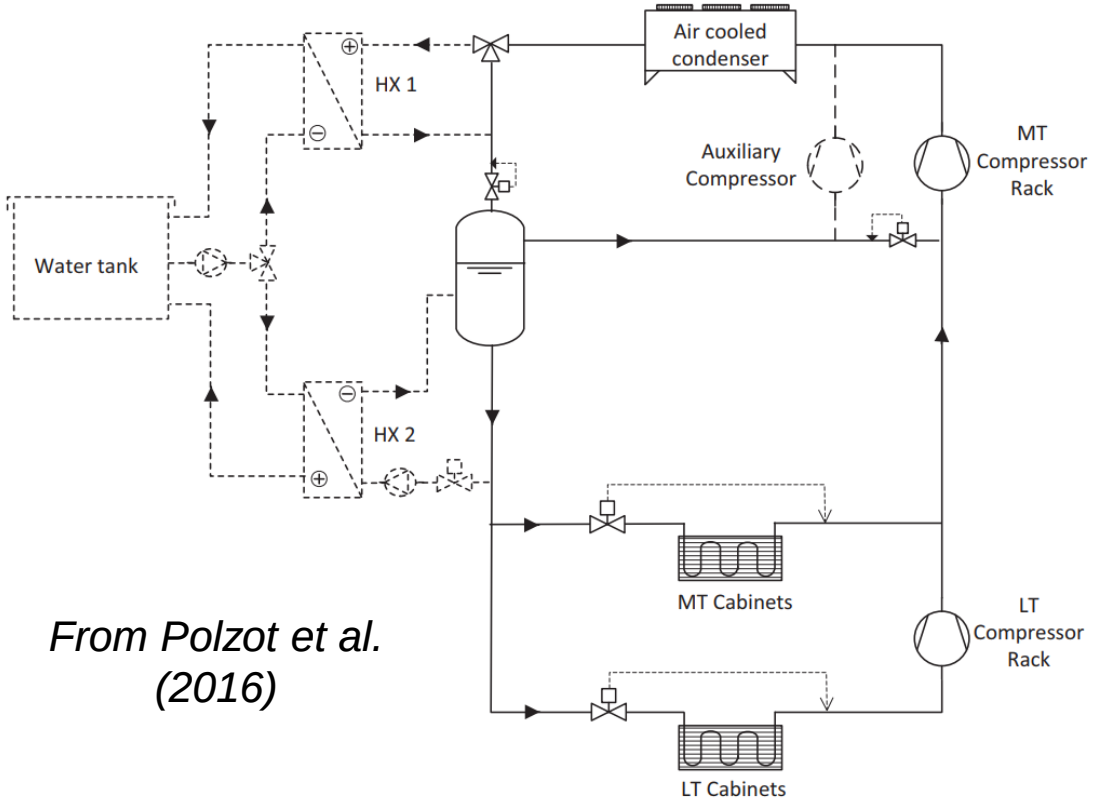
From Llopis et al. (2018)





Other solutions

WATER TANK



From Polzot et al. (2016)

GAS COOLER WITH SPRAYED WATER

LUVE, from Lozza et al. (2007)

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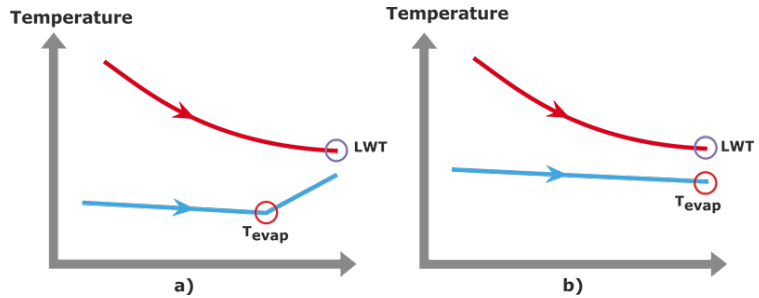
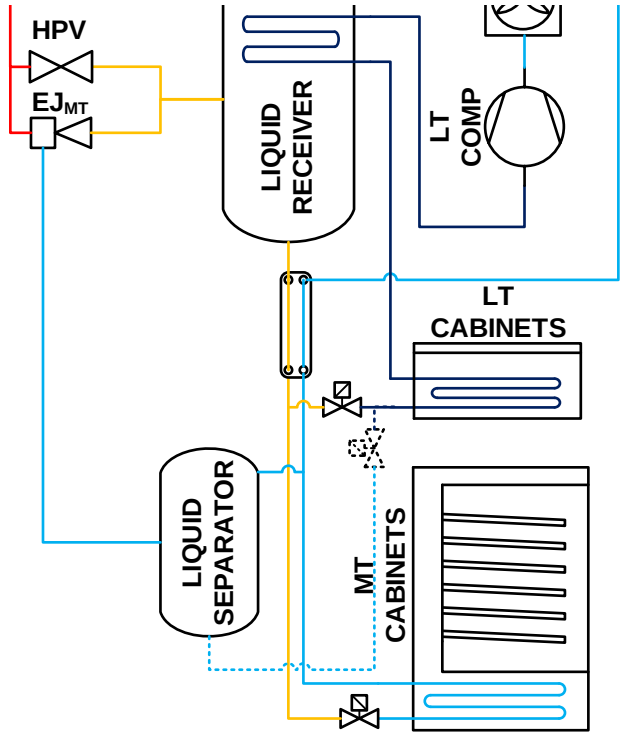
- **Flooded evaporators**
- Integration of demands
- Cold storage

Flooded evaporators

- Enhancement for any climate
- Eliminate superheat evaporators in cabinets
  - Better use of the surface → ↑T_{evap} → ↓Consumption
  - Fewer desfrosting cycles
- Liquid separtor is needed to protect compressors
- System to empty separator
  - Liquid ejectors
  - Pumps
  - Liquid line to LT cabinets (dashed line). EPTA solution



From Swep Refrigerant Handbook



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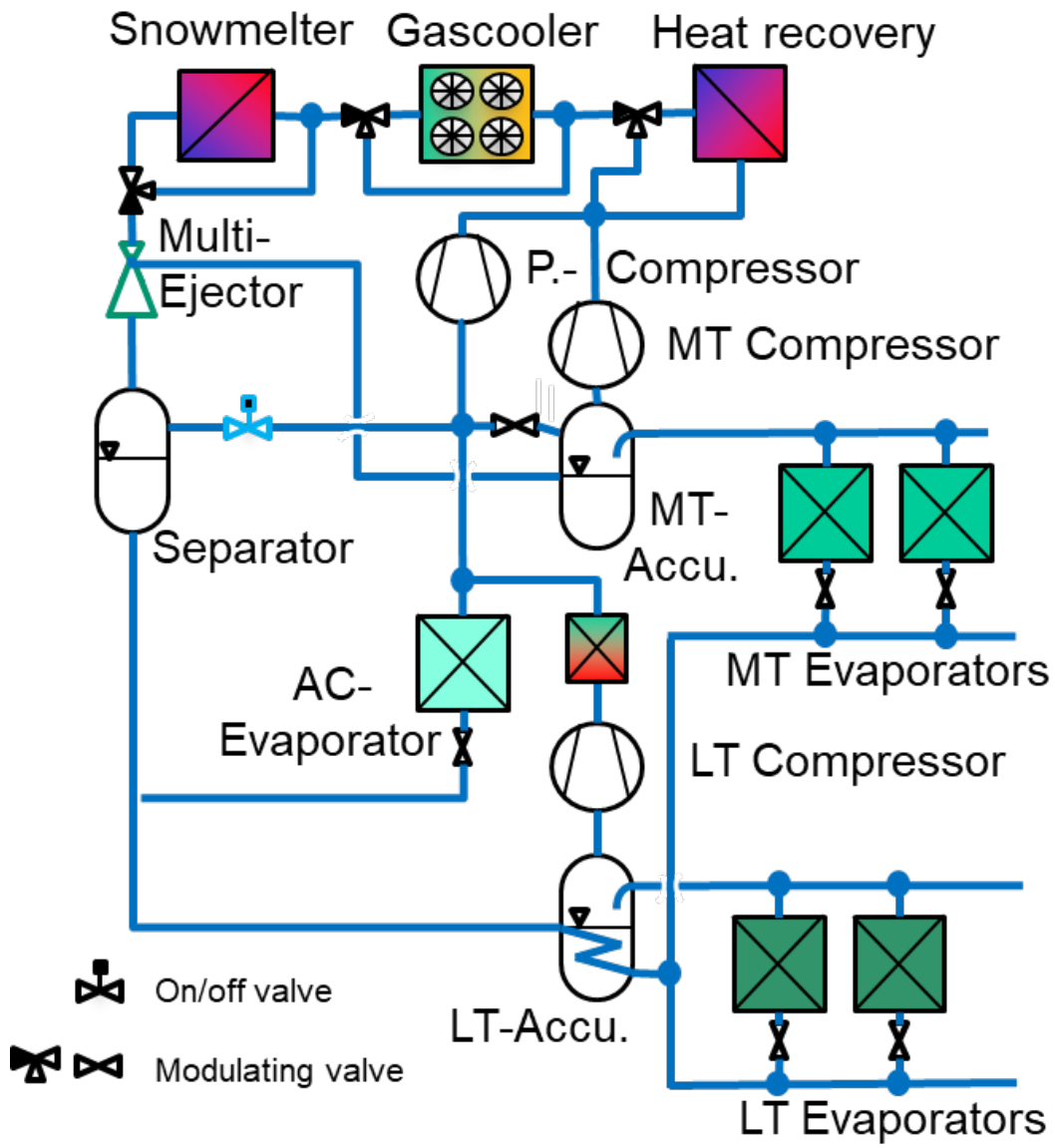
- **Integration of demands**
- Cold storage

Integration of demands

- Use heat available
  - DHW
  - Heating
  - Air Handling Units
  - Snow melting (where needed ☺)

- Air conditioning, simple solution

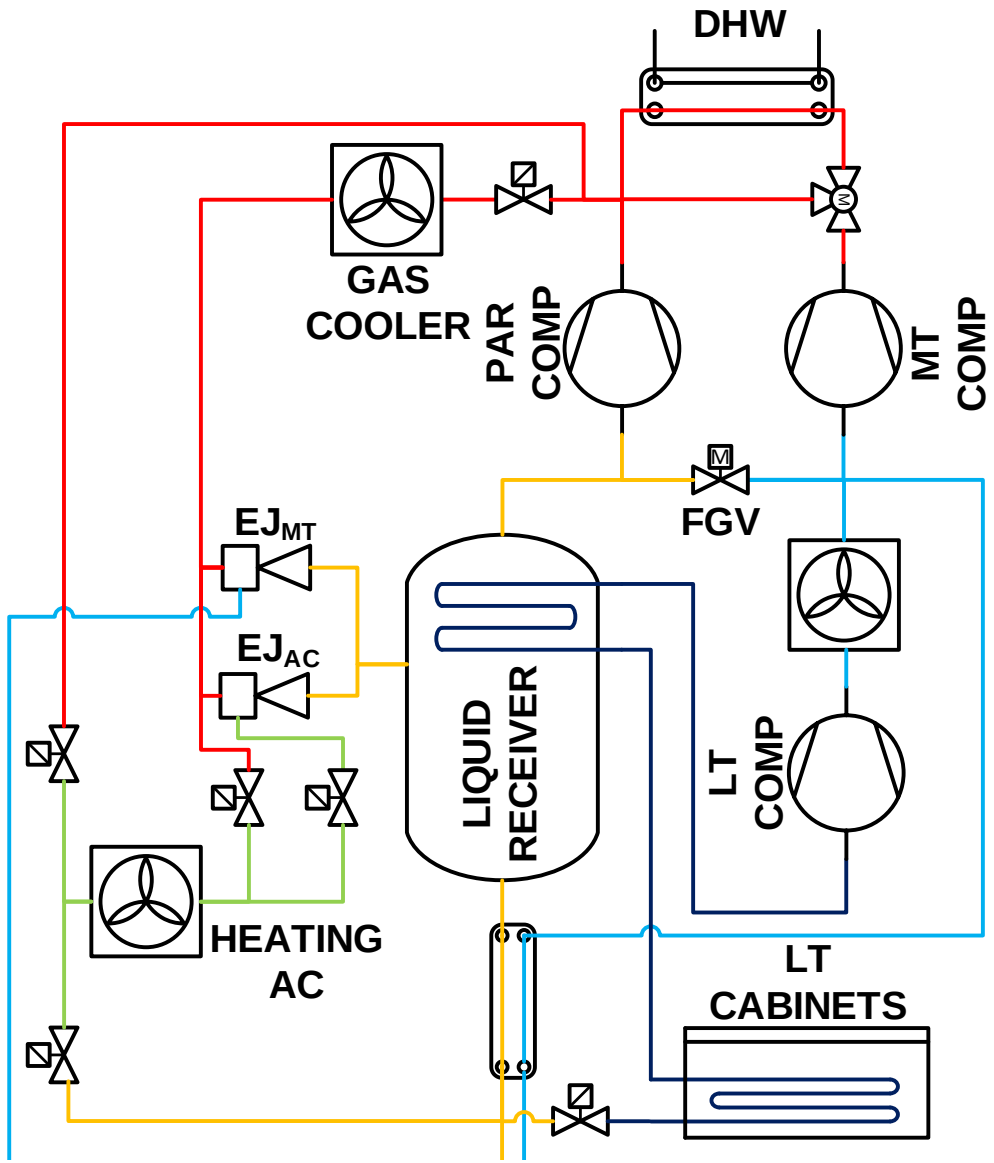
Modified from Hafner (2017)



Integration of demands

- Air conditioning with ejector

- Direct heating/cooling (AHU)
  - Eliminate the extra ΔT due to having an indirect system
  - Improve performance of all-CO_2 systems



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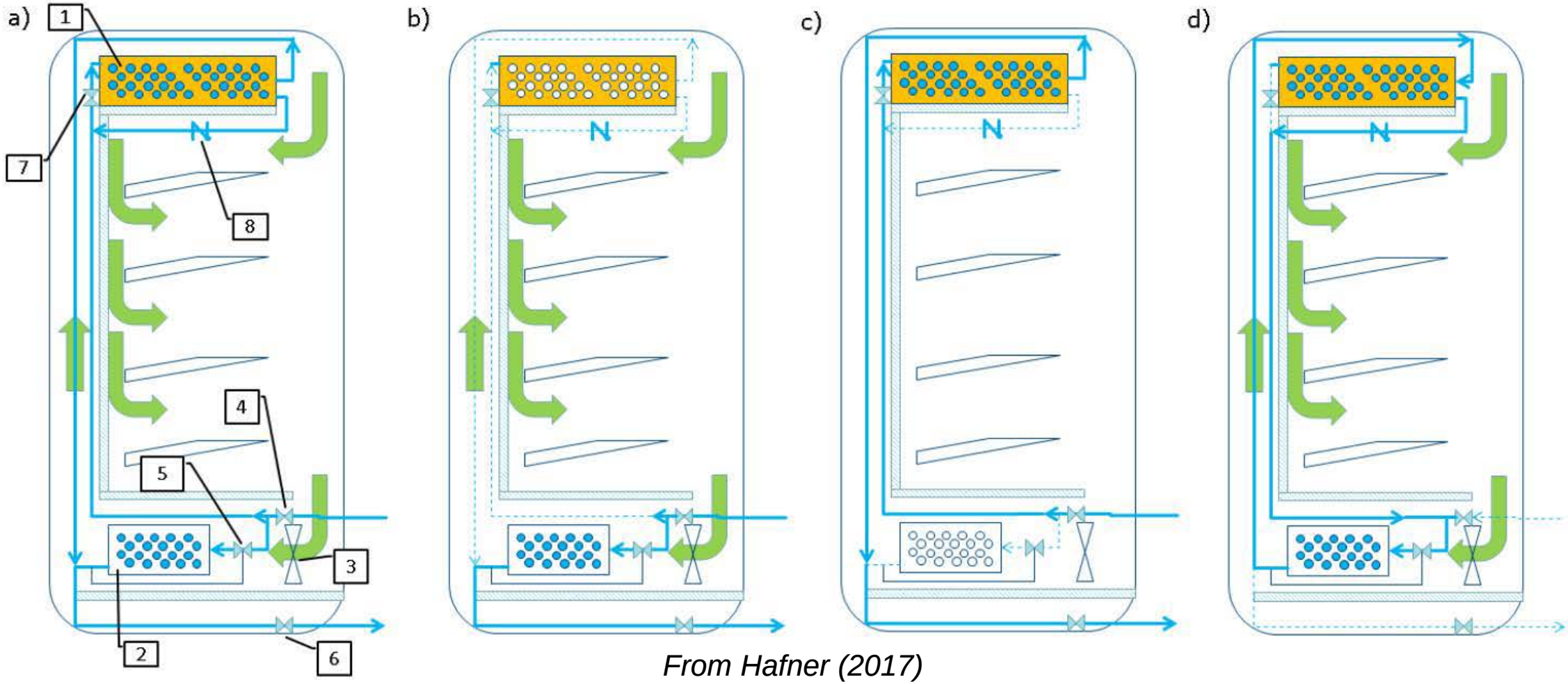
- **Cold storage**

Cold storage

a) Normal + charging modes // b) Normal mode //
c) Charging mode // d) Discharge mode (thermosiphon)



From Hafner (2017)

Summary

- **Natural refrigerants**
- **CO_2 (R744)** is a suitable solution because
  - **Predictable**, only **A1 refrigerant**
  - Booster systems + enhancements are **competitive worldwide**
  - **Training and support** is a **key for success** (that is why we are here)
- Commercial systems with CO_2 **in hot climates**
  - **Flooded evaporation**
  - **Parallel compression** and **ejector support**
  - **Integration of demands**, even direct integration
  - **Cold storage**

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Dr. Ángel Álvarez Pardiñas
Postdoctoral Researcher at Department of Energy and Process Engineering
Norwegian University of Science and Technology NTNU
angel.a.pardinas@ntnu.no