EURAMMON STUDENT'S DAY 2025

14. April 2025, Hochschule Karlsruhe

Hochschule Karlsruhe
University of
Applied Sciences

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Refrigerants, naturally!

Kaltlufttechnologie für extrem niedrige Temperaturen

Yannick Pruß
Refolution Industriekälte GmbH

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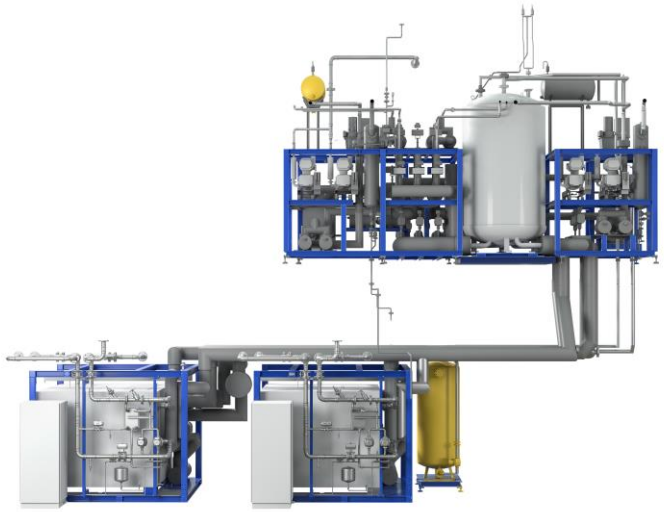
Agenda

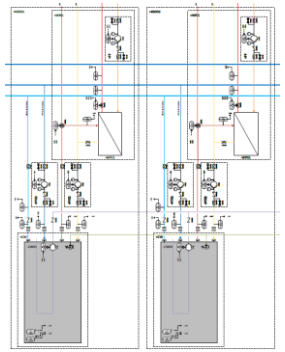
- Introduction
- Why air as a refrigerant at low temperatures?
- Basics of air cycle technology
- Applications with air cycle technology

Refolution Industriekälte GmbH

The engineering office for sustainable refrigeration

- Consulting
- Planning
- Special plant construction
- Product development





Thomas Frank
CEO
Germany

Cornelia Schröder
Assistenz
Germany

Jan Zeller
Sales Engineer
Germany

Yannick Pruss
Project Engineer
Germany

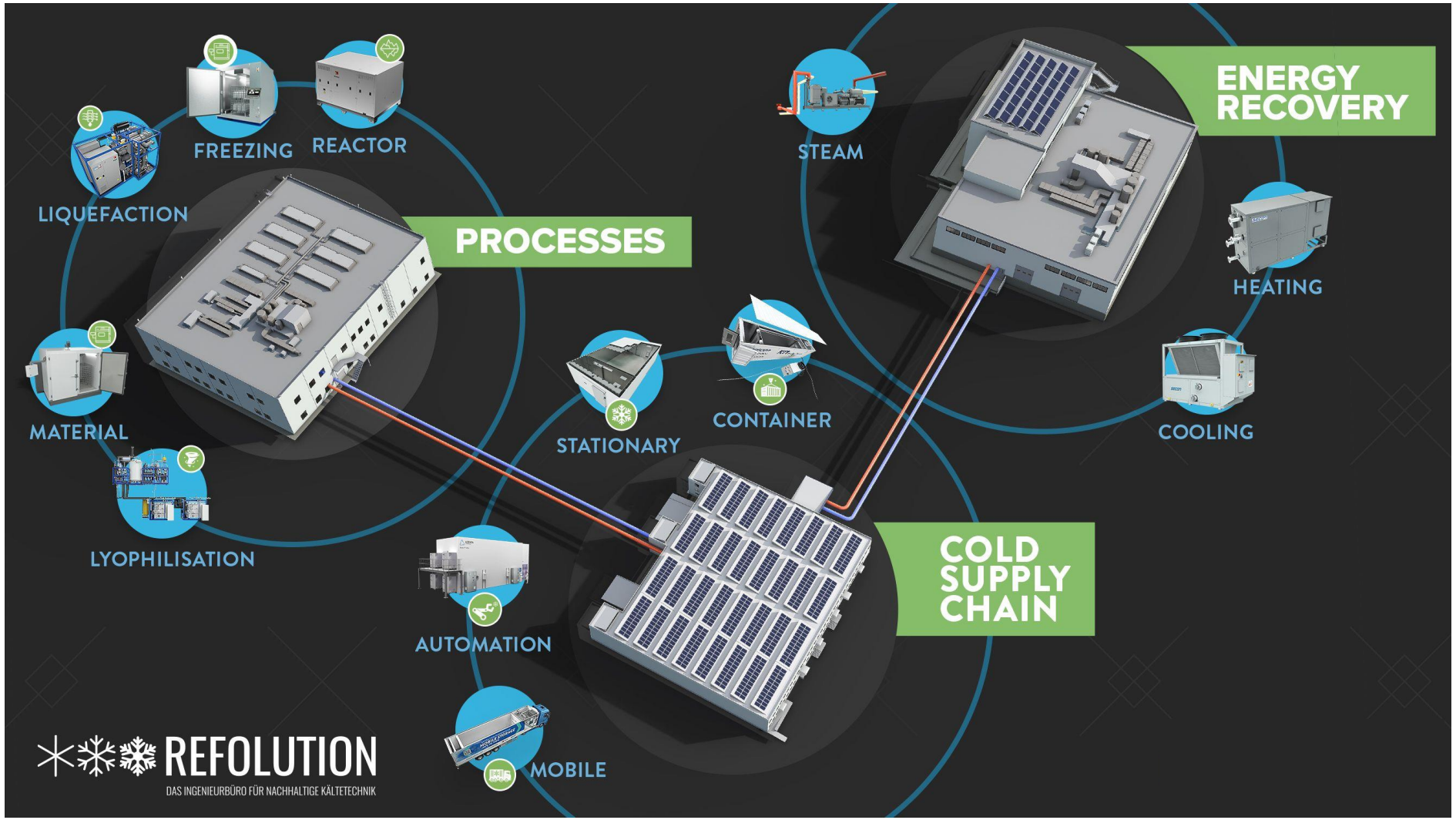
Tobias Wurz
Project Engineer
Germany

Thomas Klövekorn
Project Engineer
Germany

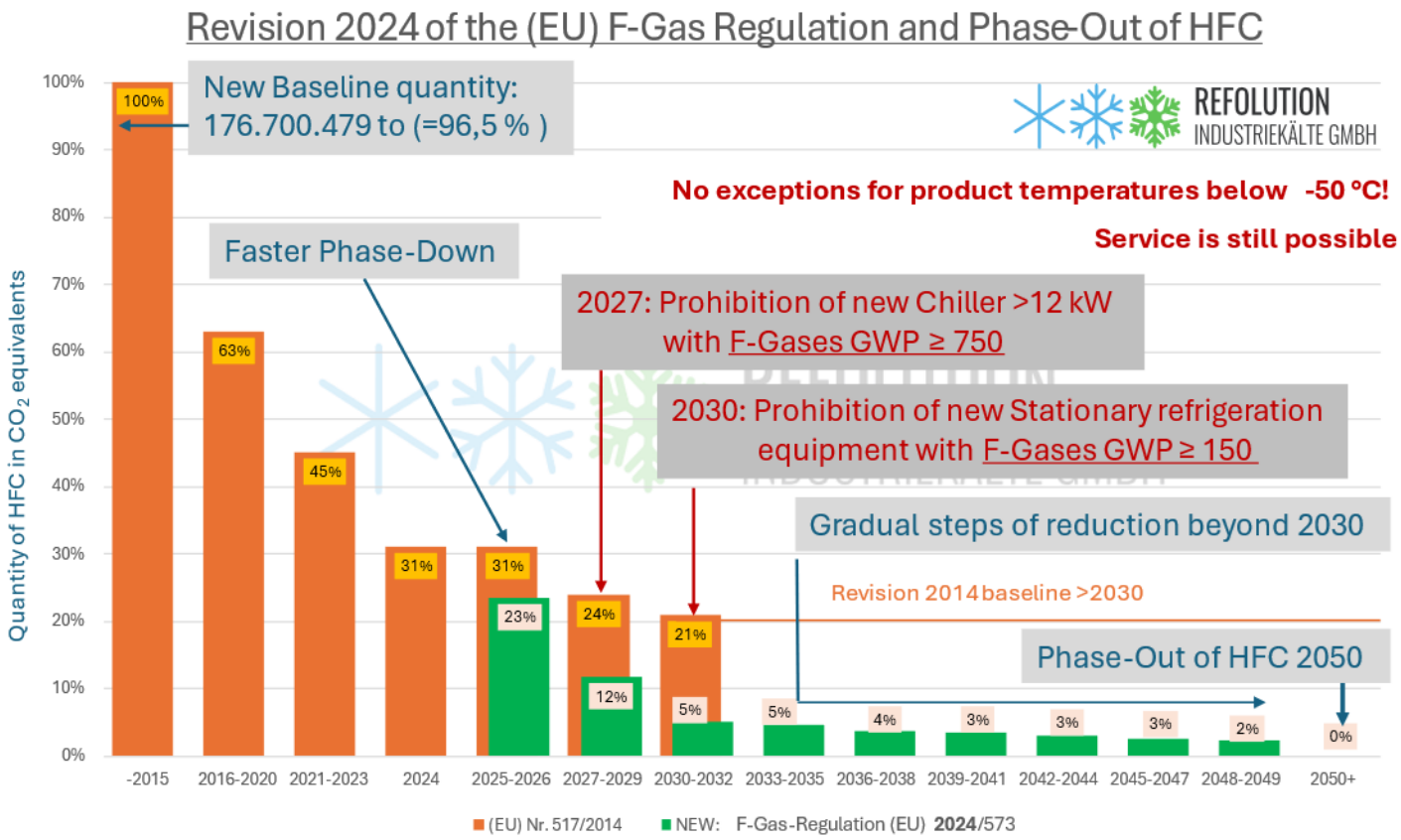
Mathias Montfort
Service
France / Lyon

Rebecca Frank
Engineering & Controlling
Germany

Refolution Portfolio



F-Gas-Regulation – Phase out of GWP



Percentage of maximum allowable quantities of hydrofluorocarbons (HFCs) placed on the market until Full Ban 2050

F-Gas-Regulation (EU) 2024/573 → 11.03.2024

Article 17: Phase-Down for HFC (HFO not in quota)

Distinction between HFC and F-Gases (HFC & HFO)

Additional bans and obligations, NEW: HFO partly included

e.g. Leakage detection of HFO with more than 1 kg

Article 11 - Prohibition of placing products on the market:

(7d) 2027: Chiller with >12 kW with F-Gases GWP ≥750

(5c) 2030: Refrigeration equipment with F-Gases GWP ≥150

Exceptions: Chillers or if required to meet safety requirements at the site of operation.

But no Exceptions for product temperatures below -50 °C!

Article 13 - Control of use of F-Gases

2032: Ban of service with virgin refrigerant GWP ≥750

Exceptions: Chillers or for product temperatures below -50 °C, but will be reviewed 2030

Examples:

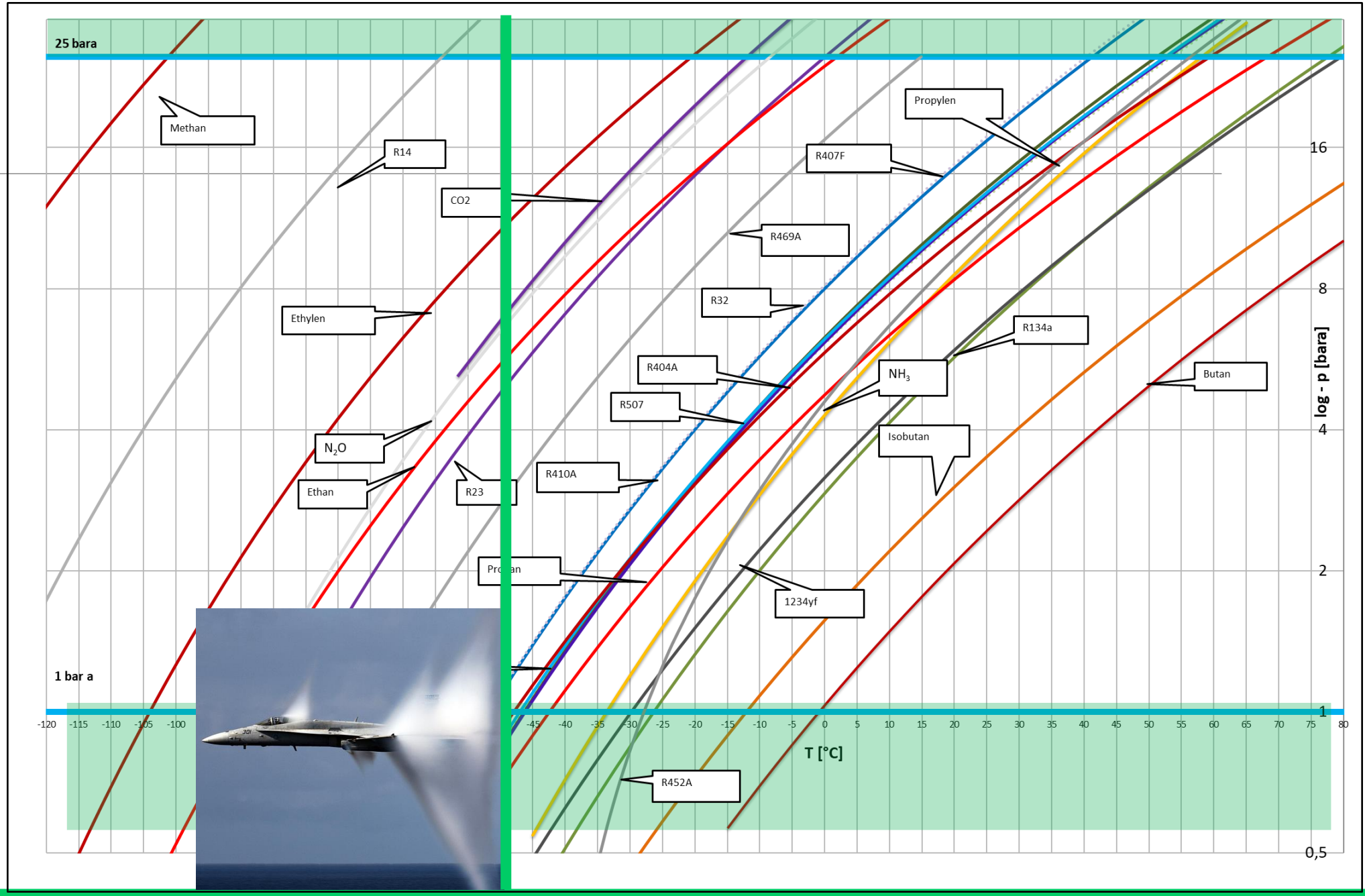
R32 – GWP 675 R410A – GWP 2088 R452A – GWP 2140

R404A – GWP 3922 R23 - GWP 14800

Refrigerants Overview

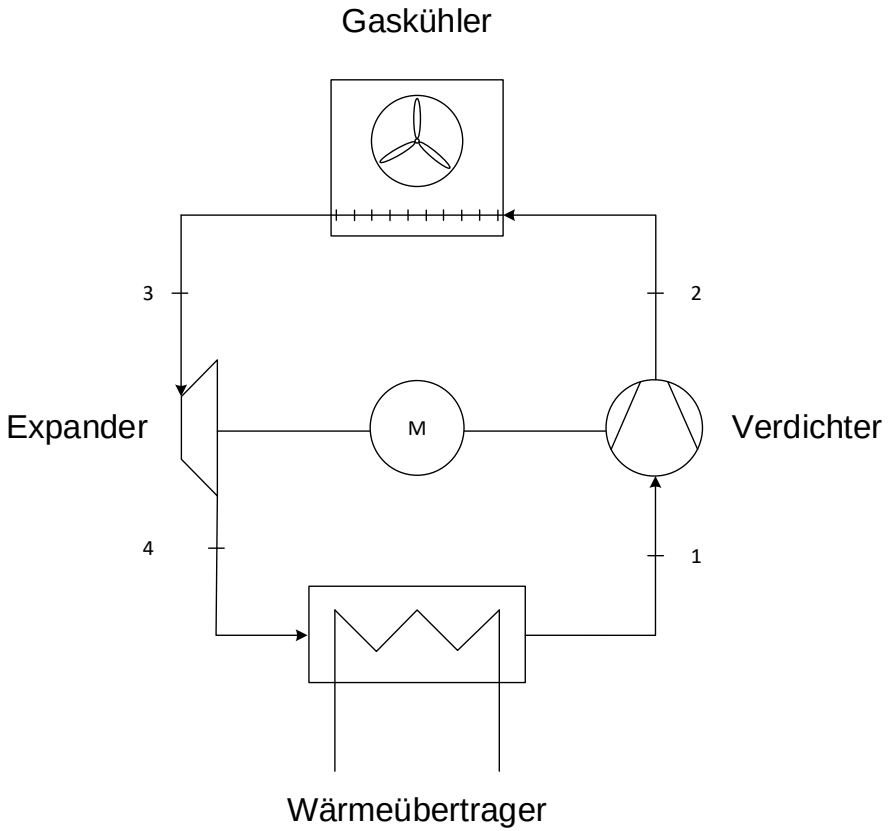
- NH3 R717 (GWP 0)
- CO2 R744 (GWP 1)
- R23 (GWP 14.800)
- R134a (GWP 1.430)
- R404A (GWP 3.922)
- R407F (GWP 1.825)
- R410A (GWP 2.088)
- R449A (GWP 1.397)
- R507A (GWP 3.985)
- 1234yf (GWP 4)
- R32 (GWP 675)
- Butan R-600 (GWP 4)
- Isobutan R-600a (GWP 3)
- Propylen R-1270 (GWP 2)
- Propan R-290 (GWP 3)
- Ethan R-170 (GWP 6)
- Ethylen R-1150 (GWP 4)
- Methan R-50 (GWP 25)
- WT69 R469A (GWP 1.357)
- R452A (GWP 2140)
- R14 (GWP 7390)
- N2O R744A (GWP 265)

„Sound barrier“ below -50°C use temperature

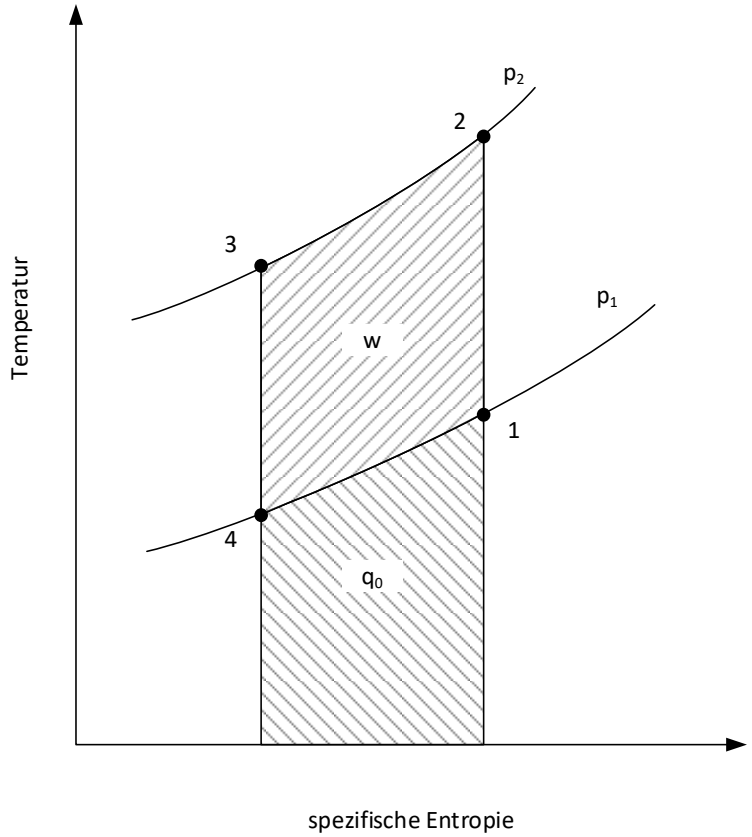


Principles of air cycle refrigeration

Closed air cycle:



Joule cycle:



Process steps:

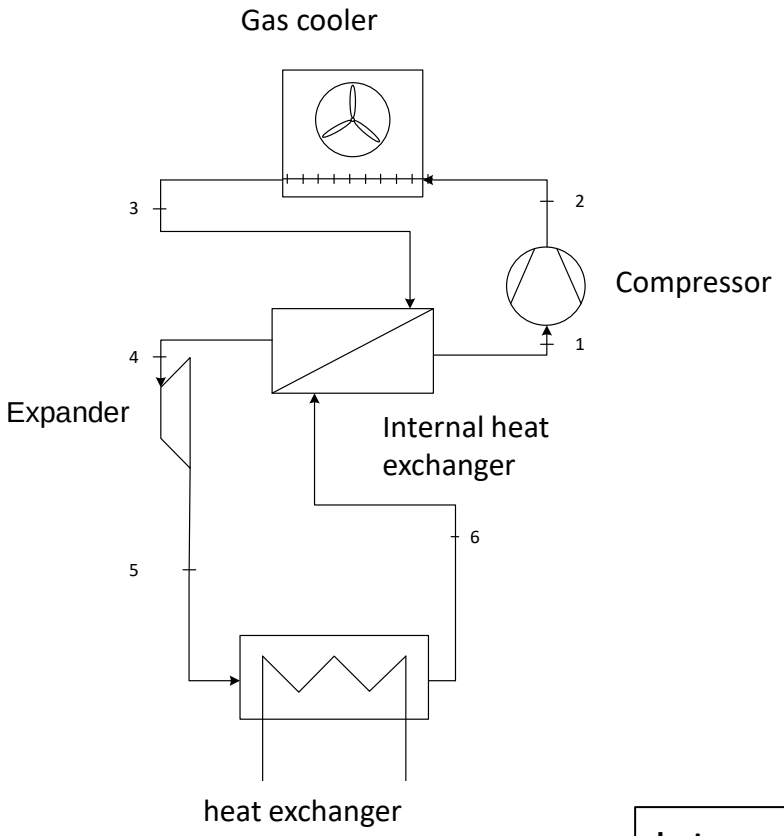
$1 \rightarrow 2_{is}$ isentropic compression

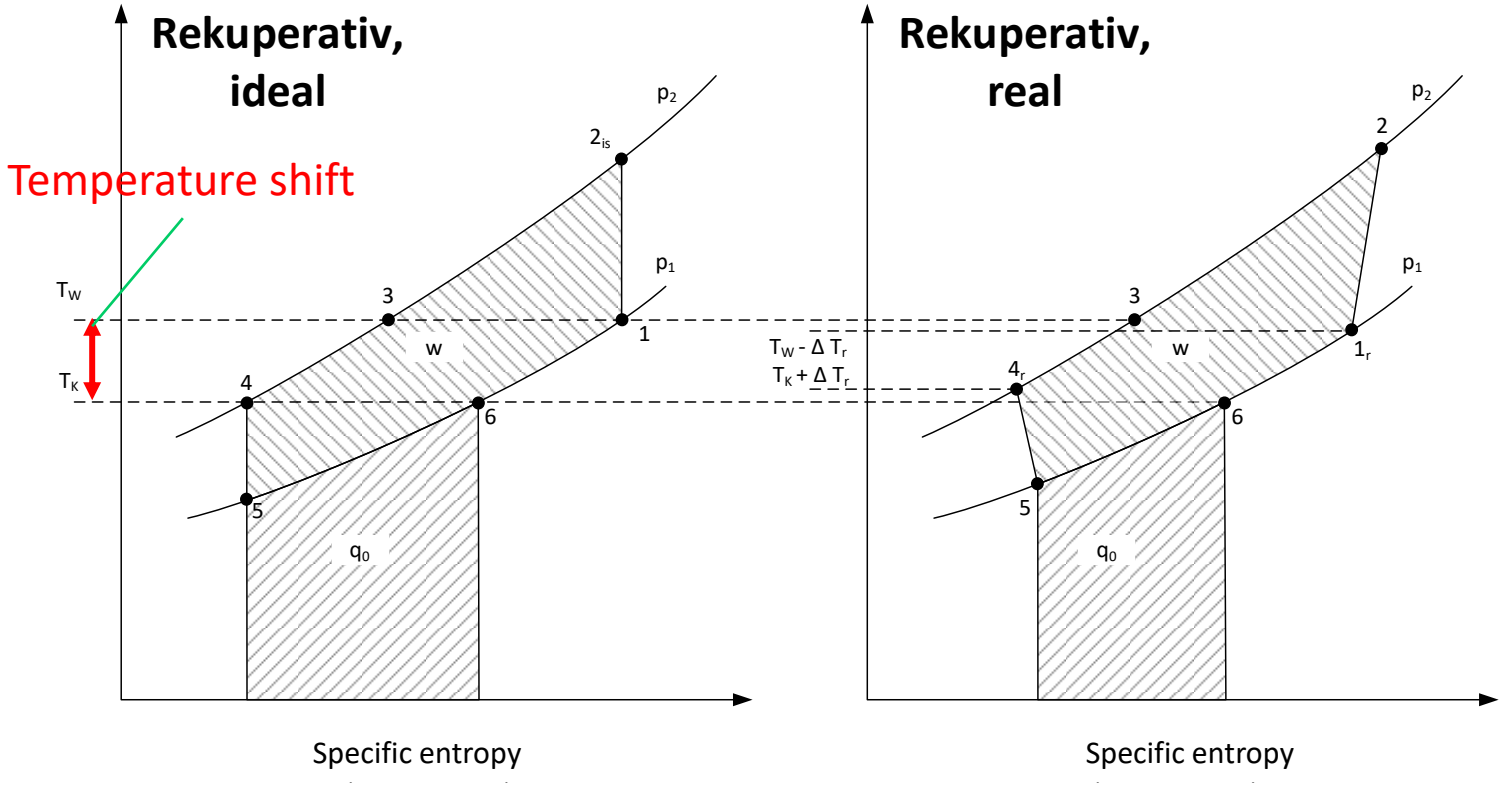
$2 \rightarrow 3$ isobaric heat rejection

$3 \rightarrow 4_{is}$ isentropic expansion

$4_{is} \rightarrow 1$ isobaric heat addition

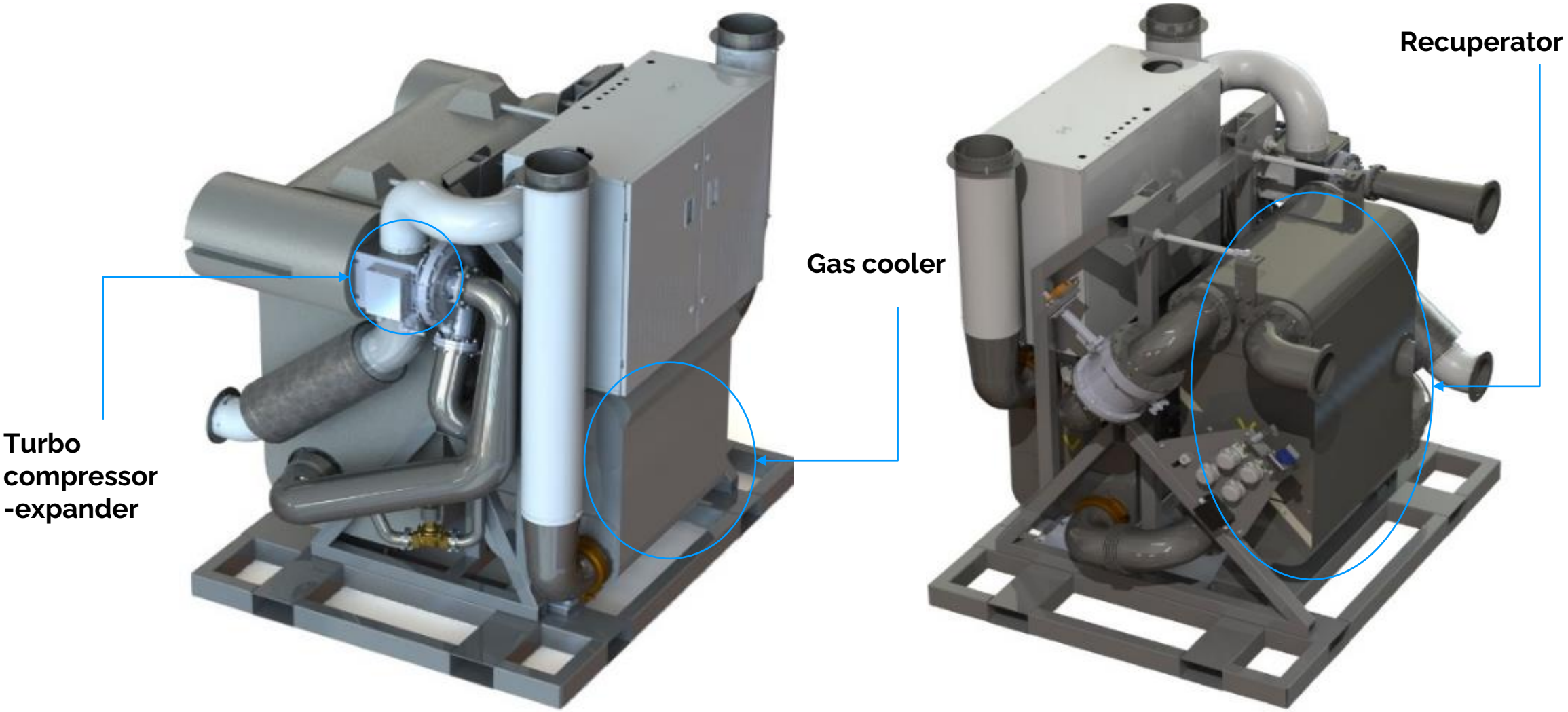
Air cycle refrigeration for low temperatures





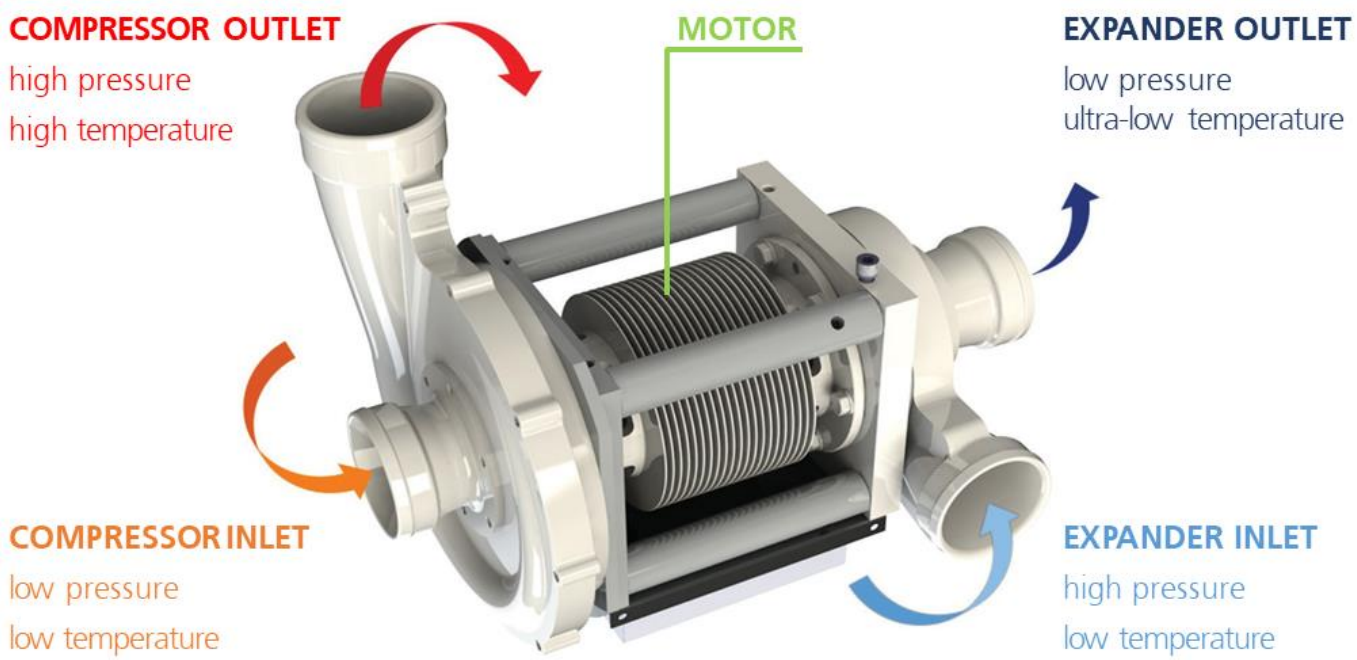
Internal heat exchanger required to be efficient at low temperatures

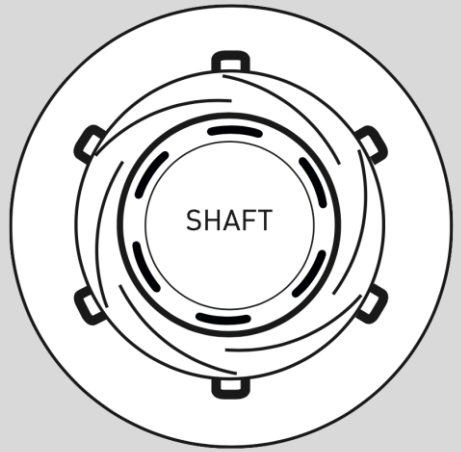
Inside the Mirai Intex refrigeration machine



Mirai Turbo-Module

- Compressor and Expander sharing **one shaft**
- Energy **recuperation**
  - Expander → Compressor
  - Up to 30 % of energy savings
- Use of **air bearings**
  - No contacting pairs
  - No oil
  - No wear





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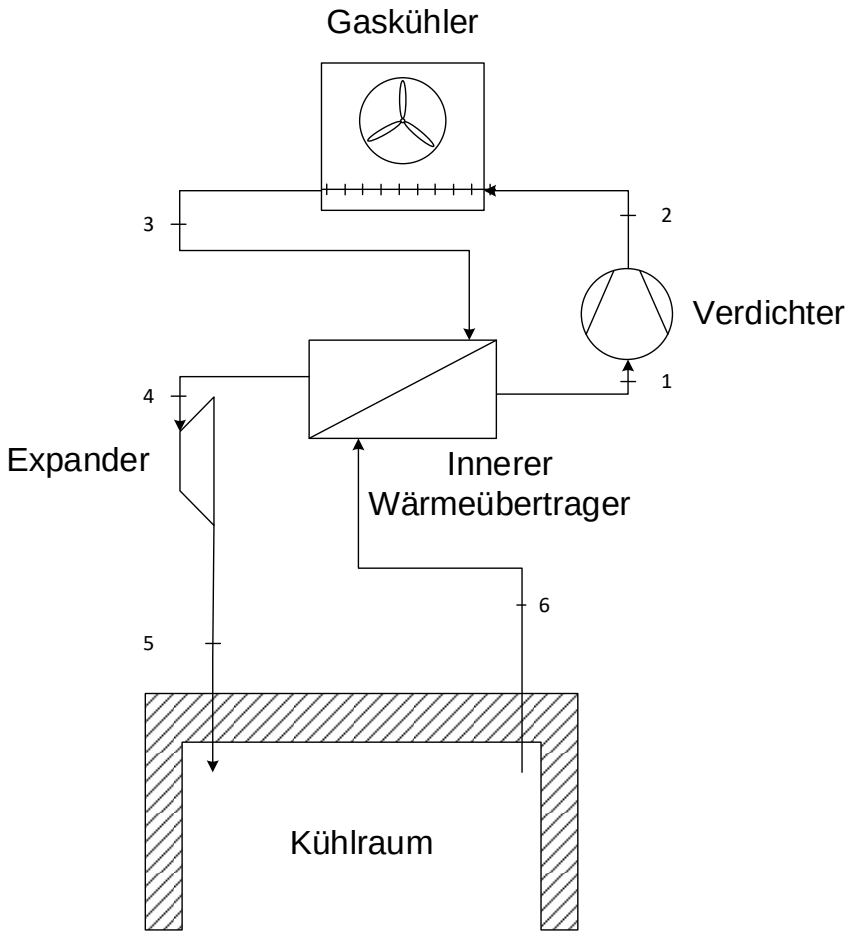
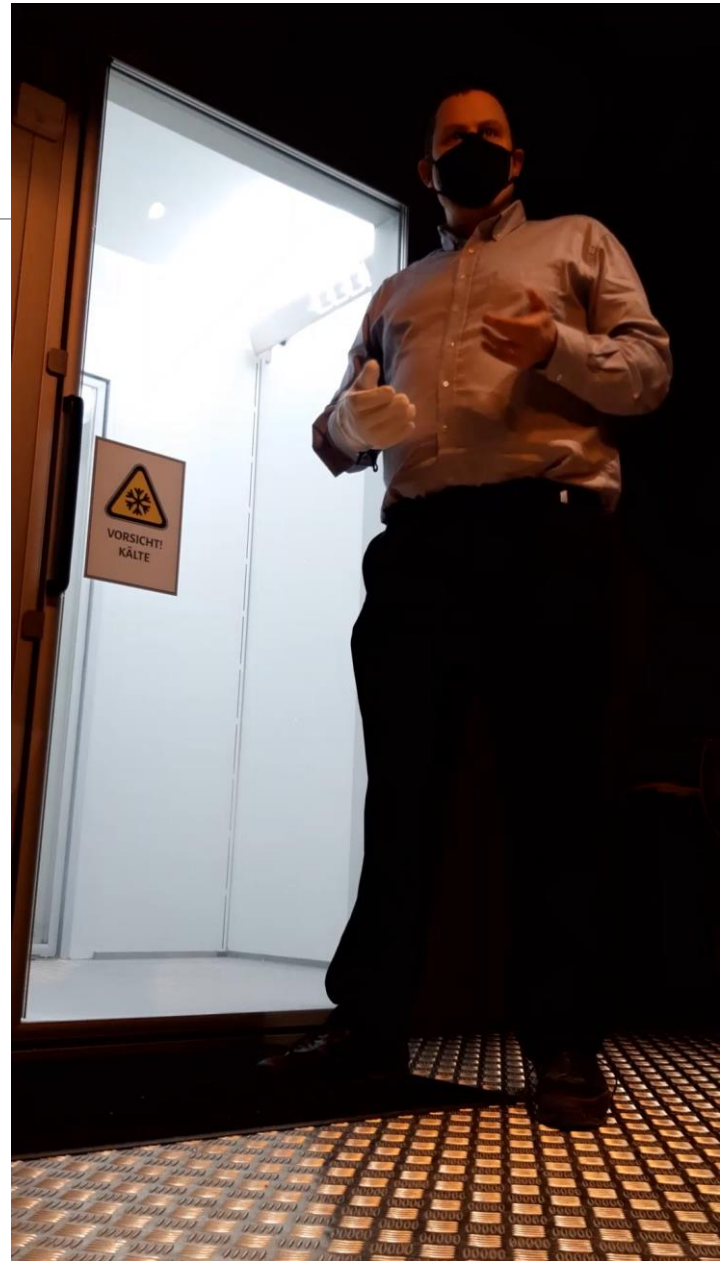
Open cycle applications



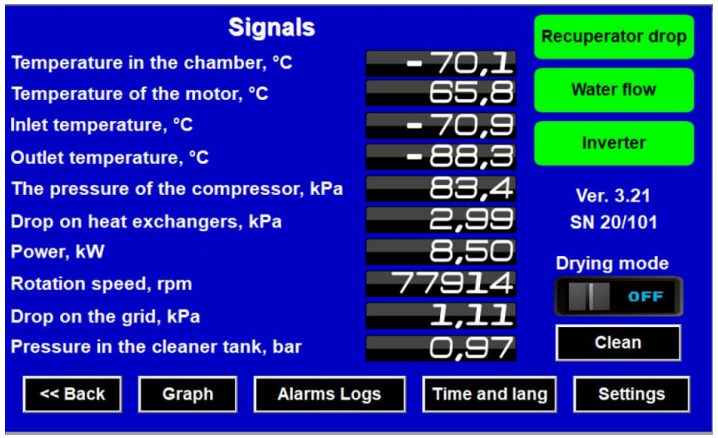
- No heat exchanger on the low temperature side
- No exegetic loss at low temperatures
- Air circulation already part of the process

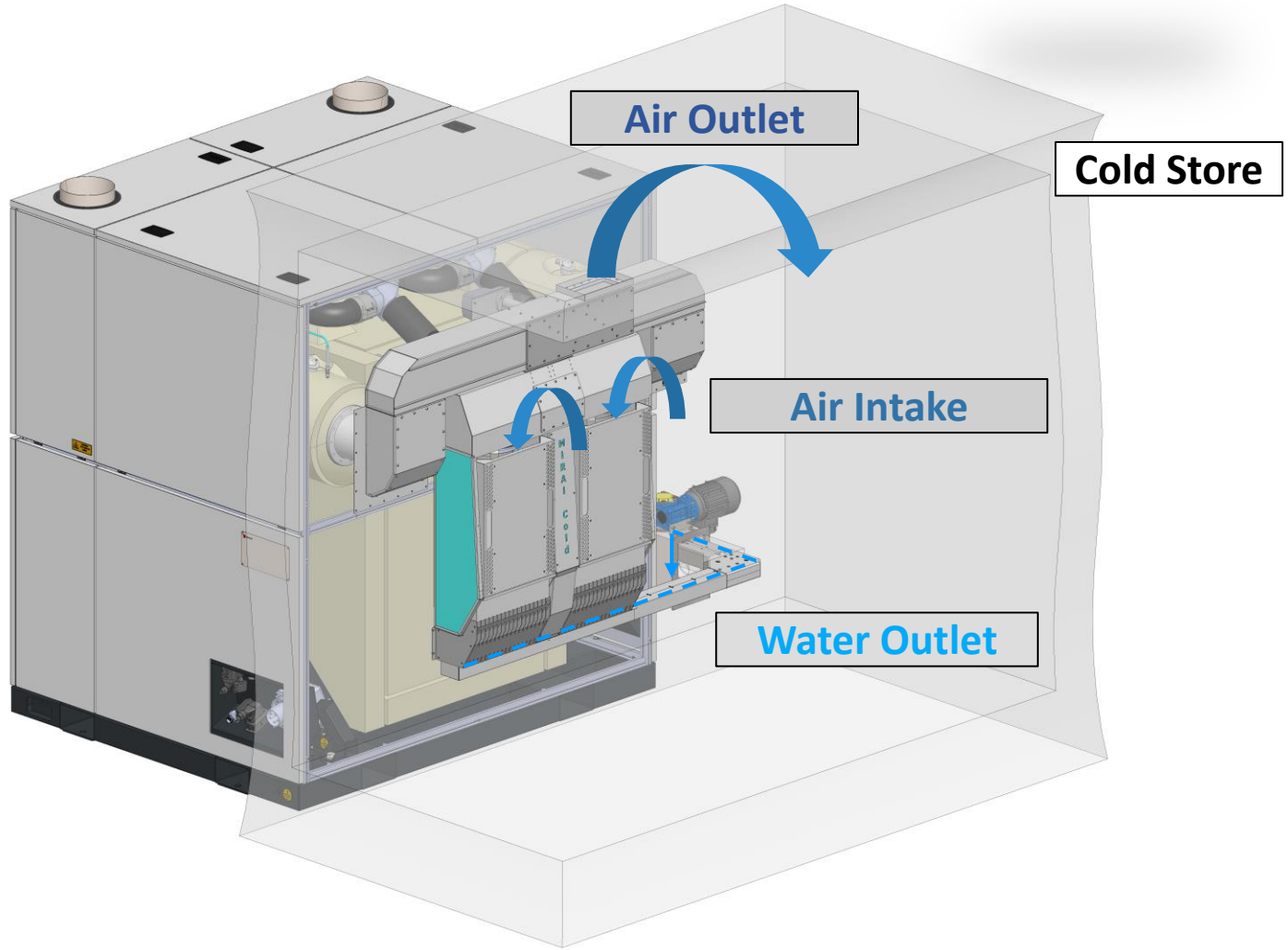
Protection of the suction side is needed to avoid clogging!



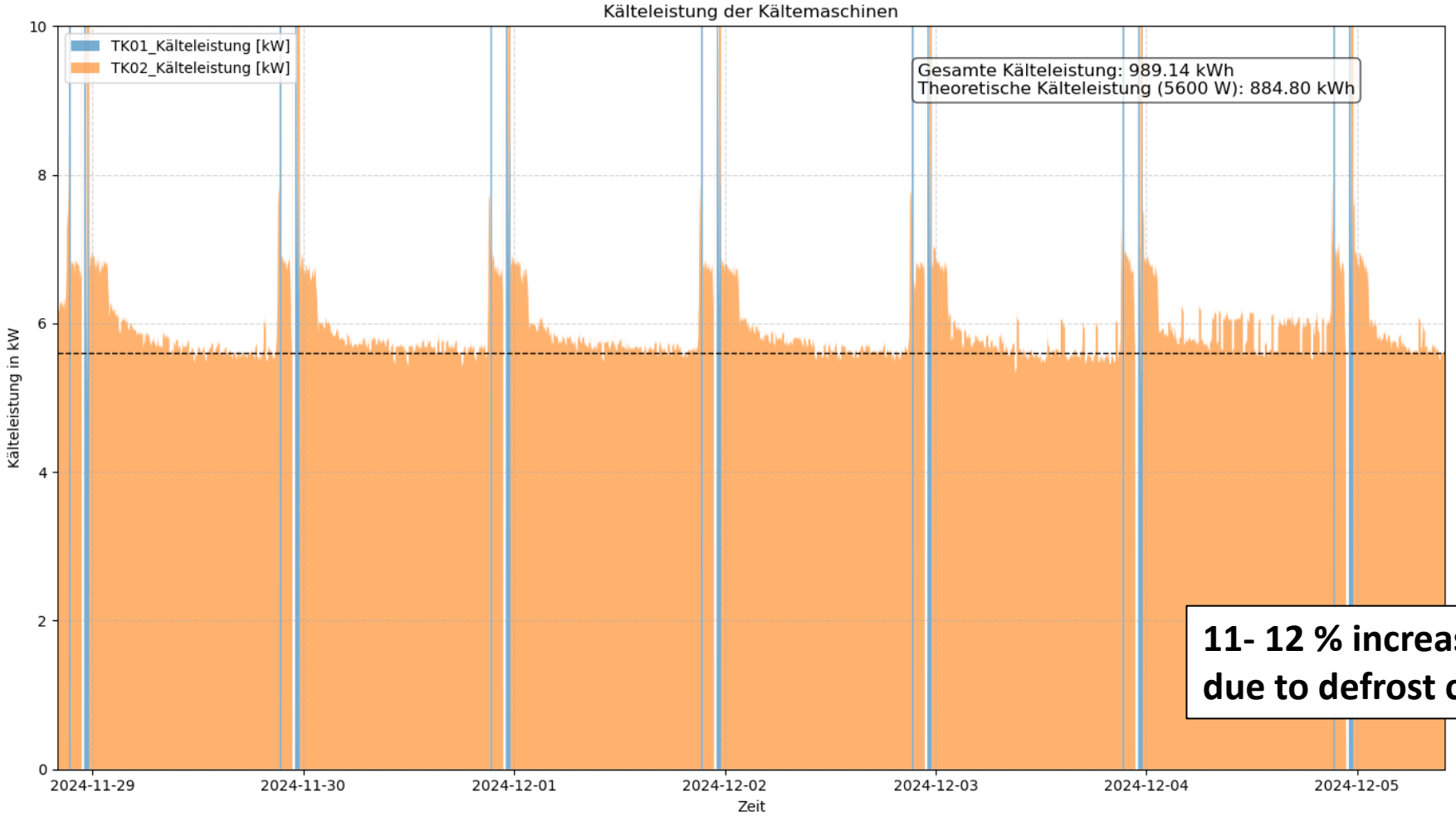
Humidity extraction device - No Evaporator

- ✓ Constant temperature (no defrost)
- ✓ No heat from ventilators and heaters
- ✓ Automated efficient de-icing
- ✓ Low Dewpoint





Effects of defrost at low temperatures



Calculations:

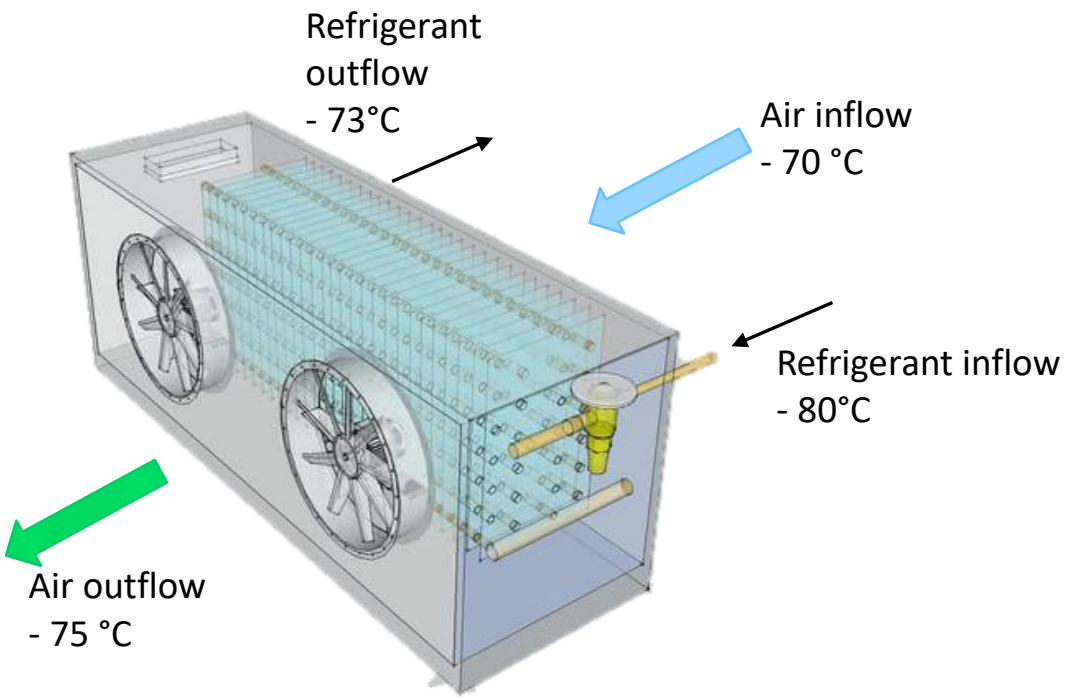
- Refrigeration capacity of R23 stage
- Based on electrical power of compressor and pressure readings

Results:

- 5,6 kW stationary heat load

11- 12 % increase in netto cooling load just due to defrost cycle

Effects of defrost at low temperatures



Installed electrical power of the evaporator:

- 2x 0,4 kW fan
- 10,5 kW heating rods
- 3,45 kW tray heating

} Duration 30 min

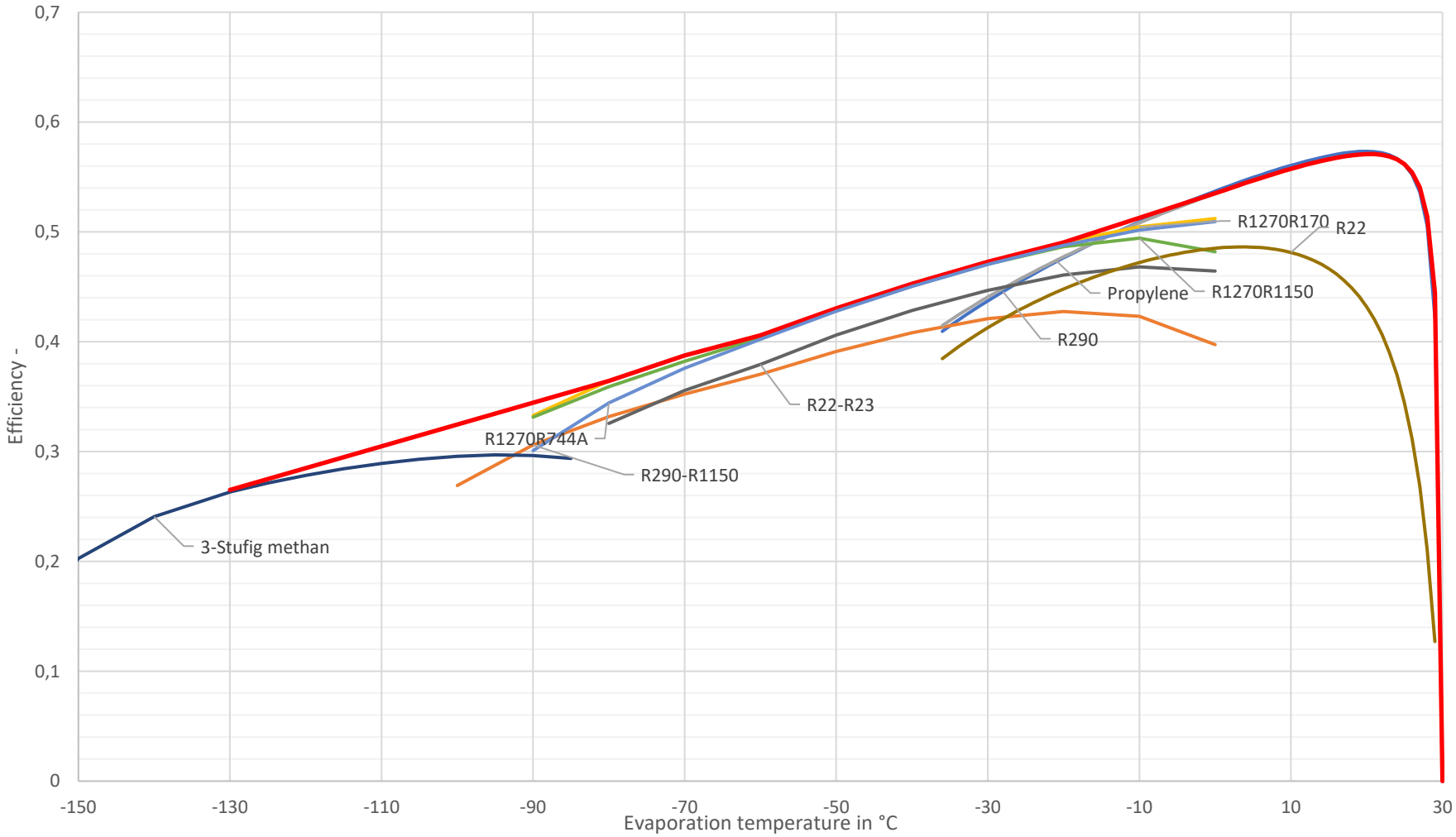
For the complete measurement of 158 h duration, 253 kWh are spent on cooling due to fan power

Stationary cooling load of compressor 884 kWh

Netto cooling load 632 kWh without defrost and fan

38 % increase of cooling load just due to fan operation

Theoretical efficiency of vapor compression



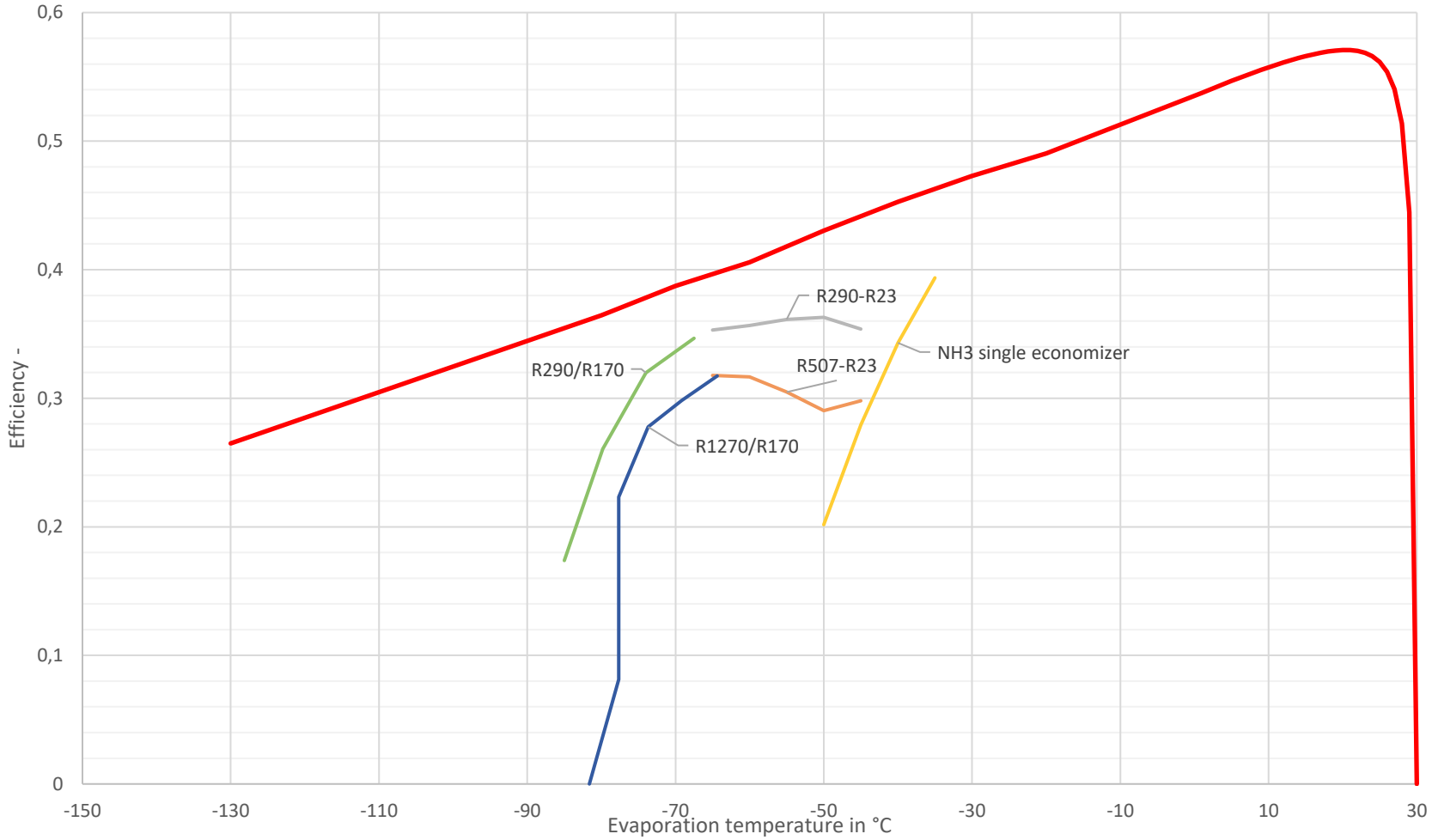
Simulation:

- Simplyfied calculation of refreigeration cycle
- Optimum middle pressure for cascade systems
- Reference temperature of 30 °C

Results:

- Function of the theoretical maximum efficiency of typical vapor compression systems

Energy comparison with mesurments



Comparison:

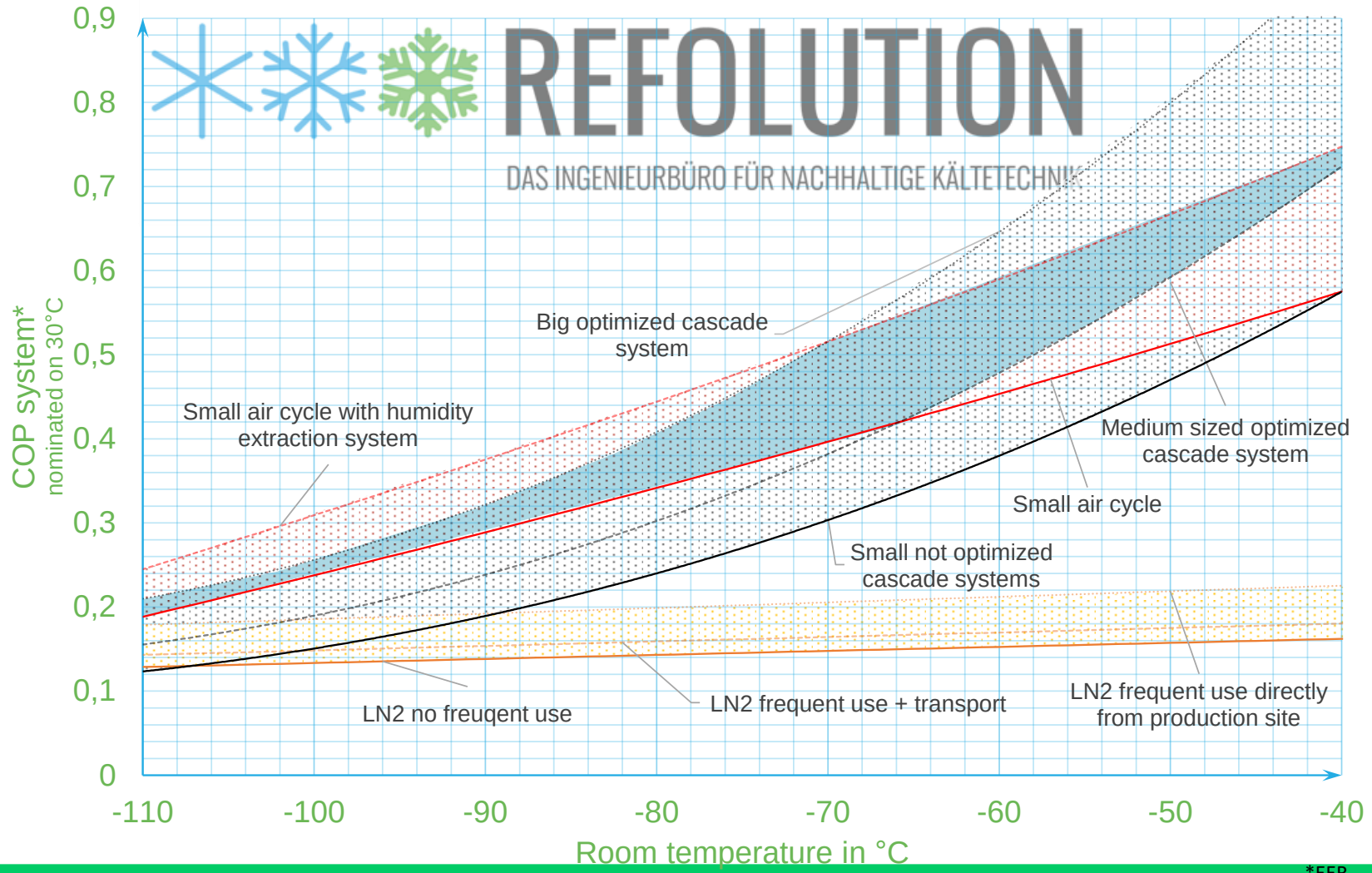
- Literature
- Own measurements

Results:

- Theoretical maximum not achieved
- Decreasing efficiency when not operated at design point

Part loads can cause significant decrease in efficiency!

Energy Comparison Full load– open cycle



*EER

Vapor compressions:

- Compensation of defrost and additional heating loads with 30 % of netto cooling
- dT evaporation to air 10 K

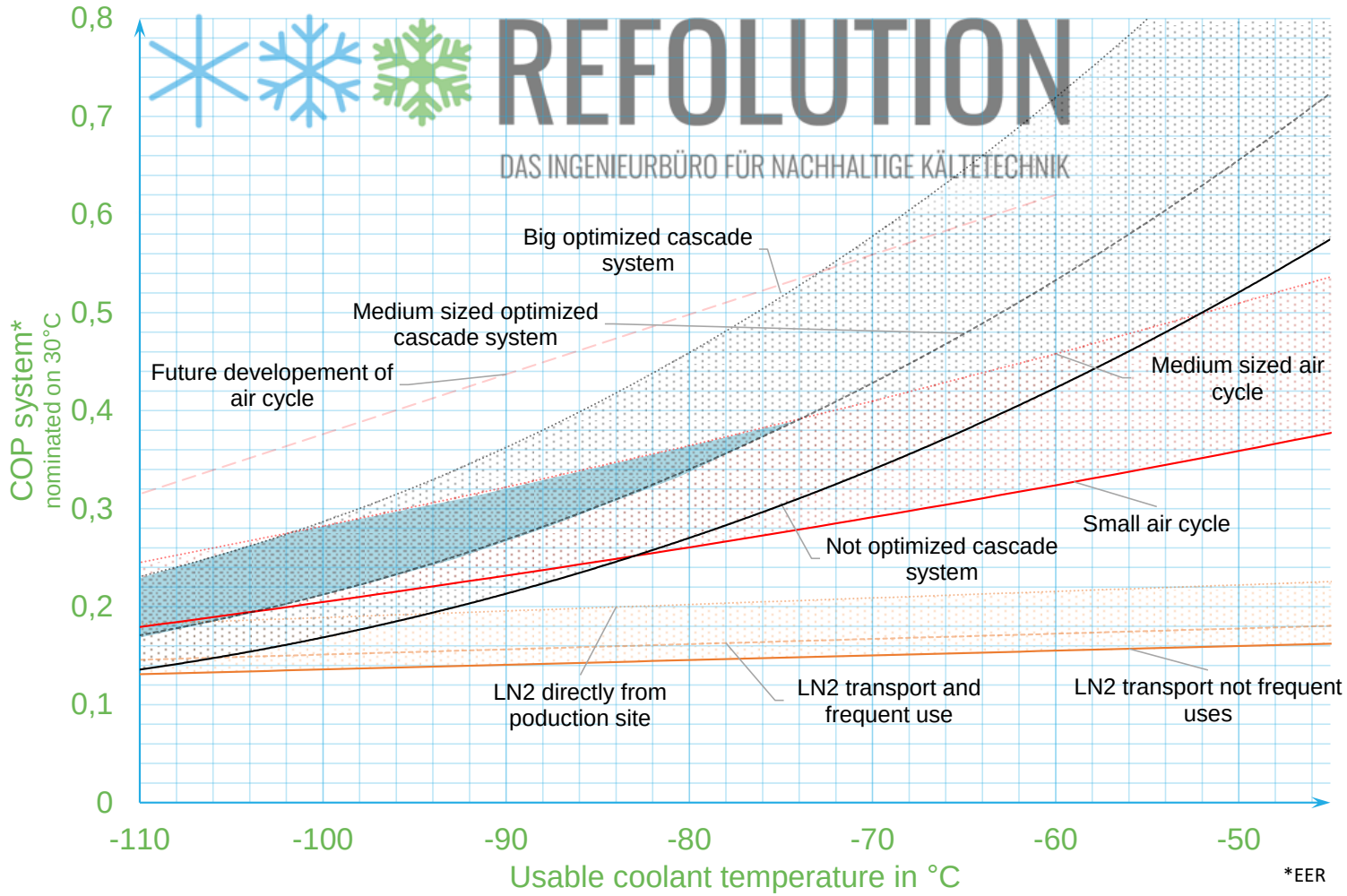
Air cycle:

- Sweet spot -60 to -130 °C
- In some applications -45 to -50 °C

Liquid Nitrogen:

- Only efficient at temperatures <-130 °C

Energy Comparison Full load– closed cycle



Cooling of secondary fluid:

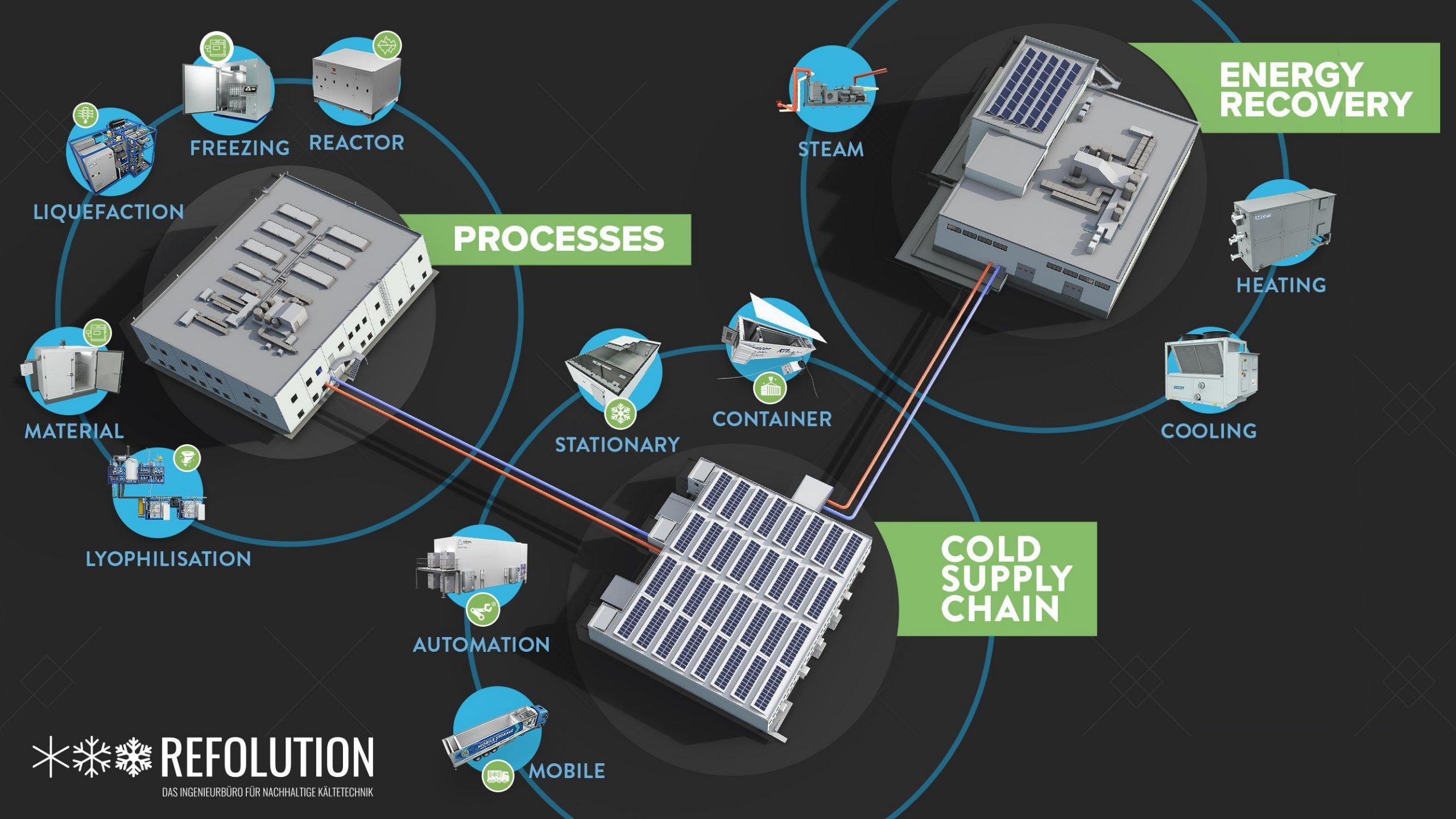
- dT evaporation to oil 10 K

Air cycle:

- Shifted Sweet spot to -75 to -130 °C
- Exergetic loss due to heat exchanger

Liquid Nitrogen:

- Only efficient at temperatures <-130 °C

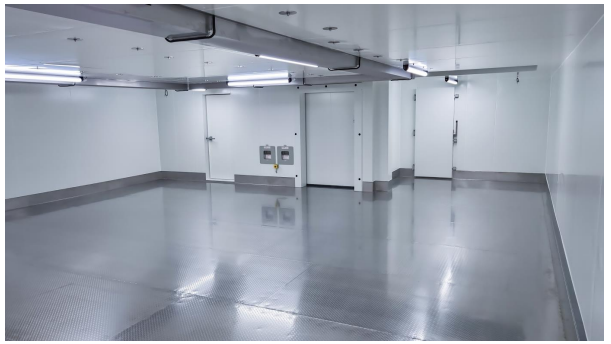

FREEZING
REACTOR
LIQUEFACTION
PROCESSES
MATERIAL
LYOPHILISATION
STATIONARY
CONTAINER
AUTOMATION
MOBILE
STEAM
ENERGY RECOVERY
HEATING
COOLING
COLD SUPPLY CHAIN
REFOLUTION
DAS INGENIEURBÜRO FÜR NACHHALTIGE KÄLTETECHNIK

Cold storage application

Flexible -20 to -160°C

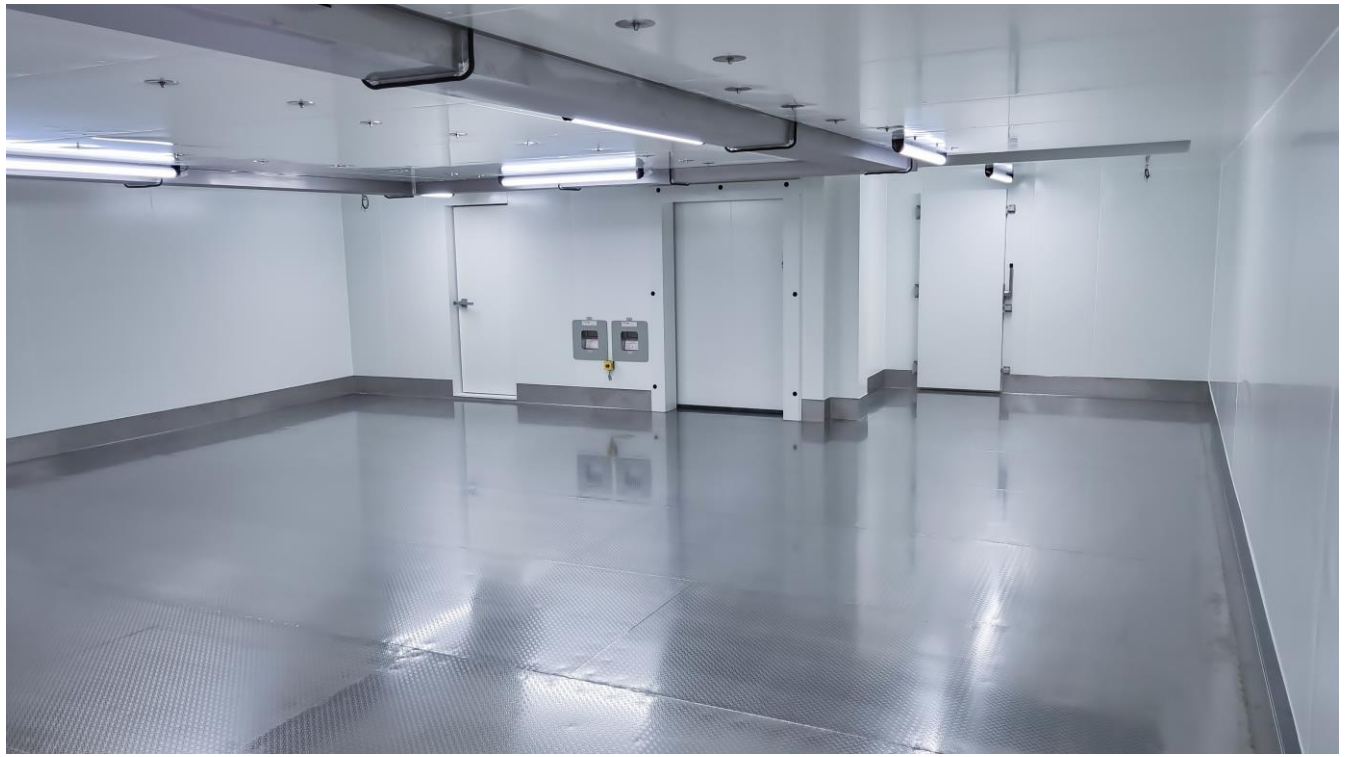
supply chain

with only air as refrigerant



Referenz Recipharm / Wasserburg

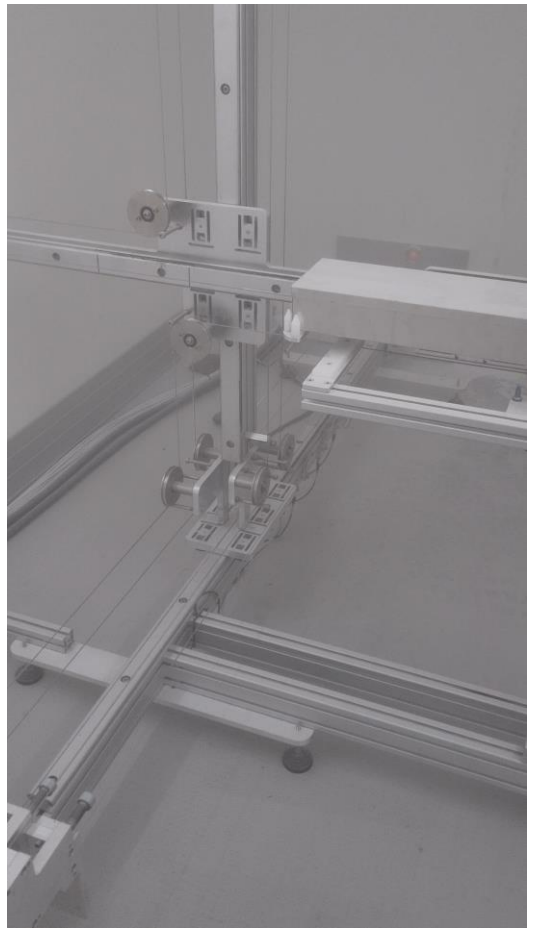
Flexible -90°C to -20°C storage rooms
2 * 185 m^3 / 85 m^2 storage space
Teledoor insulation chambers



Mirai Intex air refrigeration machines (R729)
2+1 MC10 O/W for each room
Redundant cold water supply by Secon propane chiller (R290)

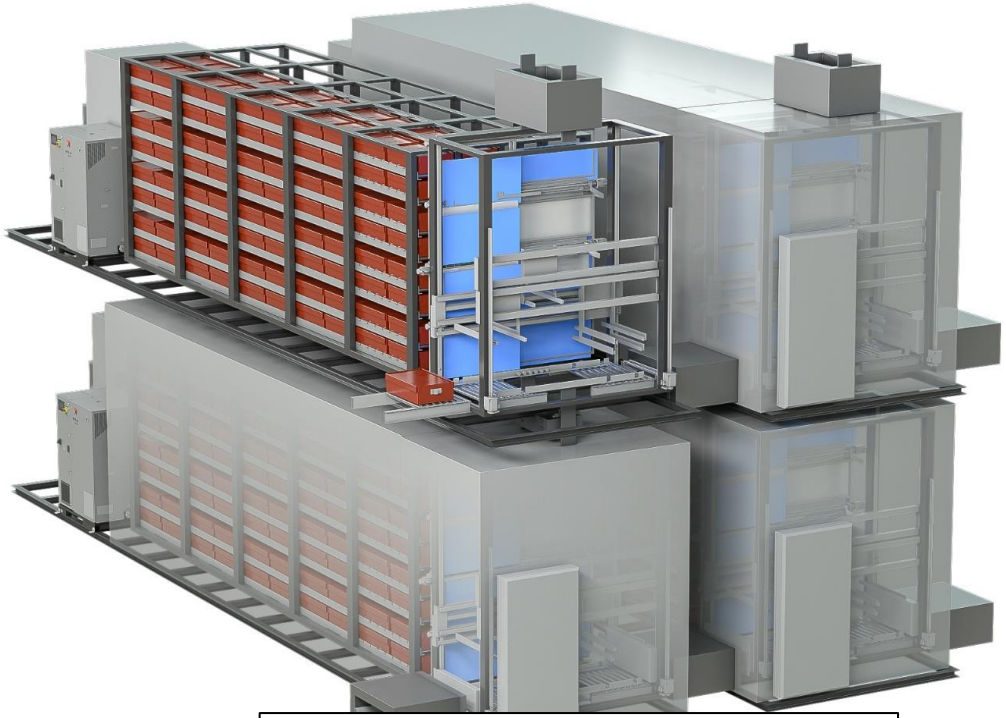
First prototype in -80°C in 2023

- ✓ Function achieved -80°C
- ✓ Minimal heat load
- ✓ Max density store enabled
- ✓ Long time Test

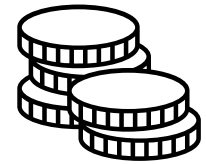


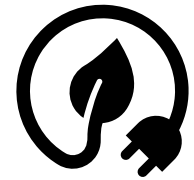
Automated Ultra-Low Temperature High Density storage – ULT HD

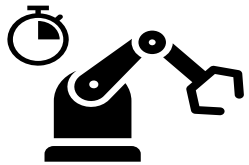
The solution is future proof with full flexibility complainant with actual and future regulation to be ready for any kind of medicine that must be frozen, stored and shipped.



Prototype currently in build up







- ✓ Future proof with high flexibility – each module -20°C down to -90°C
- ✓ 70% less space in the building needed
- ✓ 60 % less energy cost and CO2 footprint + reduced labour, qualification and service cost
- ✓ Faster access time
- ✓ Less ice on the product
- ✓ Low maintenance and long-lasting equipment
- ✓ Scalable modular solution also over time

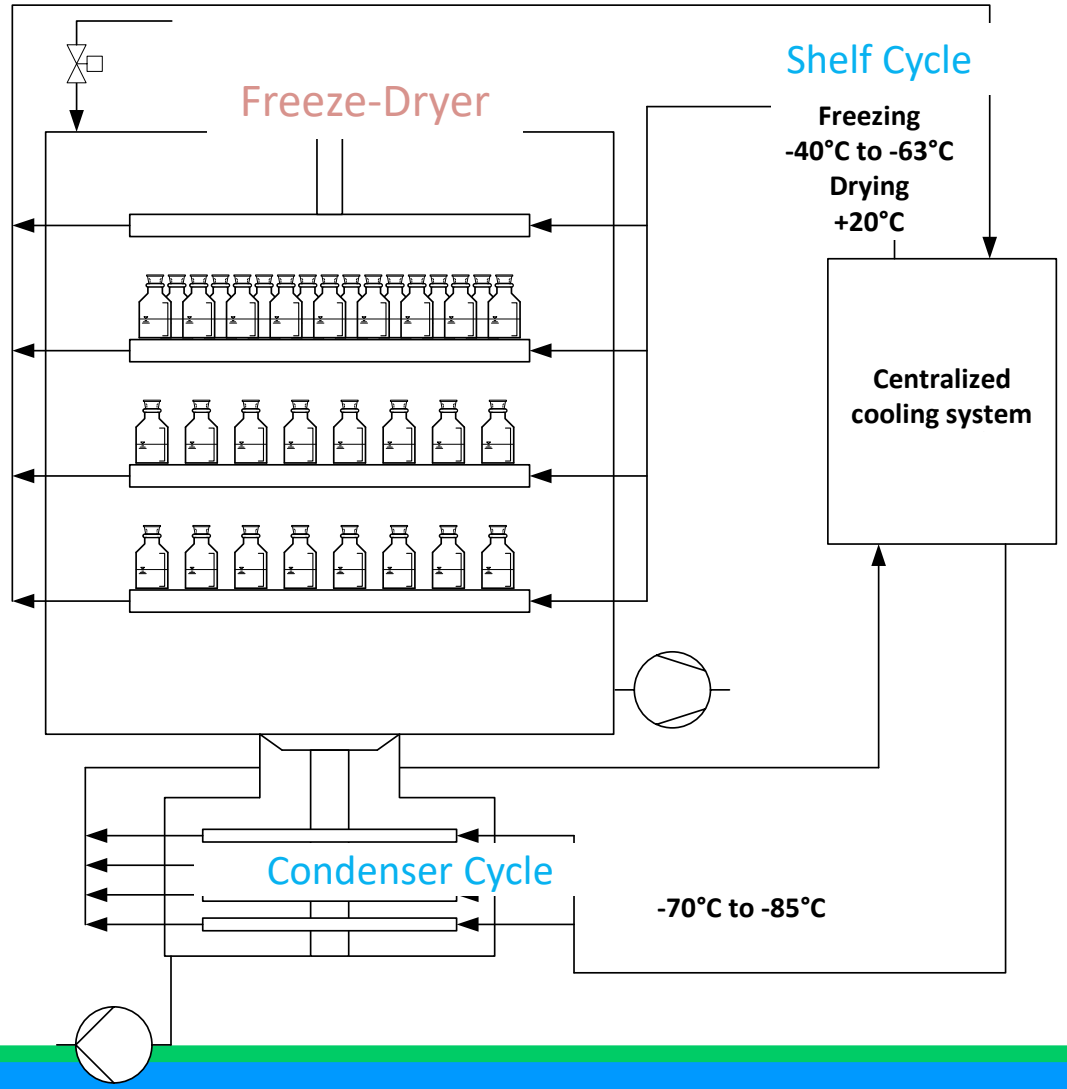
Refolution has the solutions with air as refrigerant

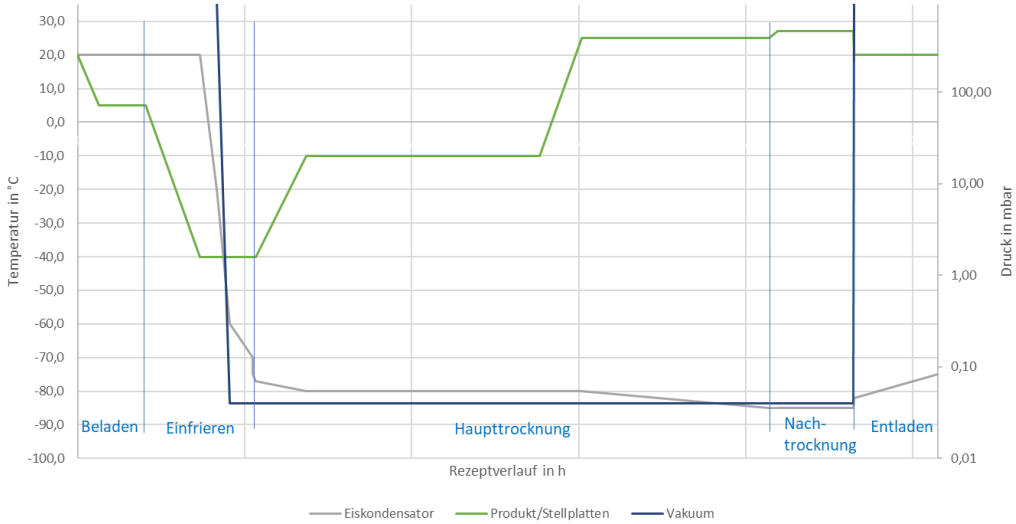
Solvent recycling

Freez and thaw unit

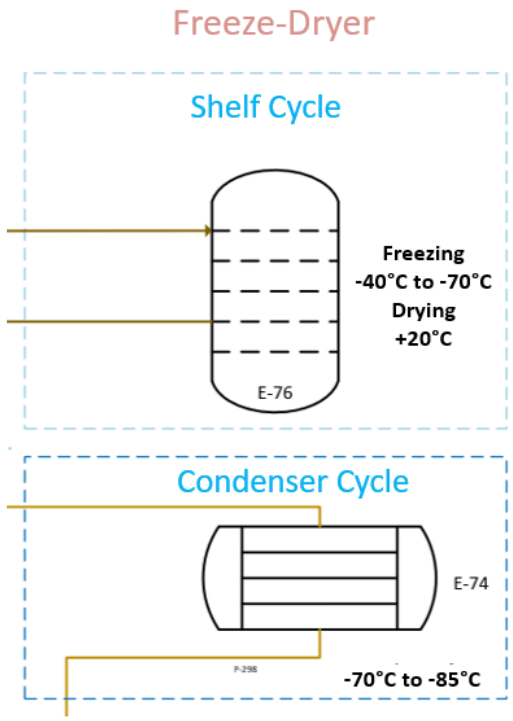
Lyophilization

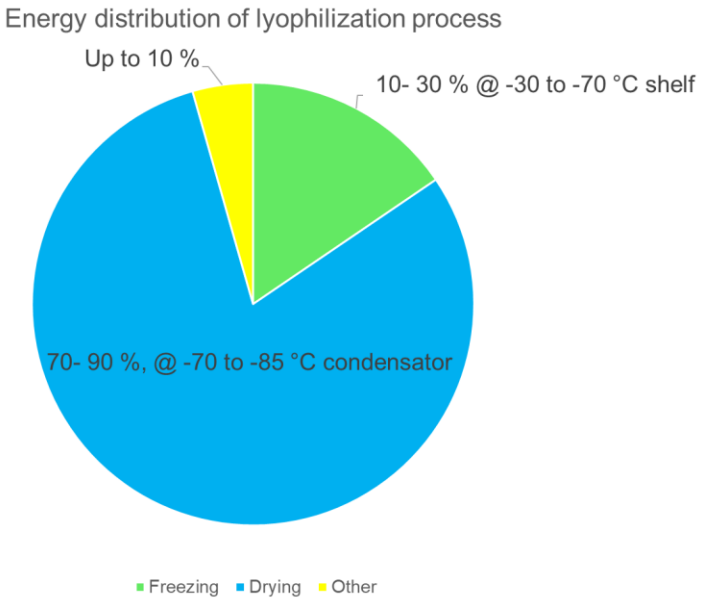
Lyophilization process

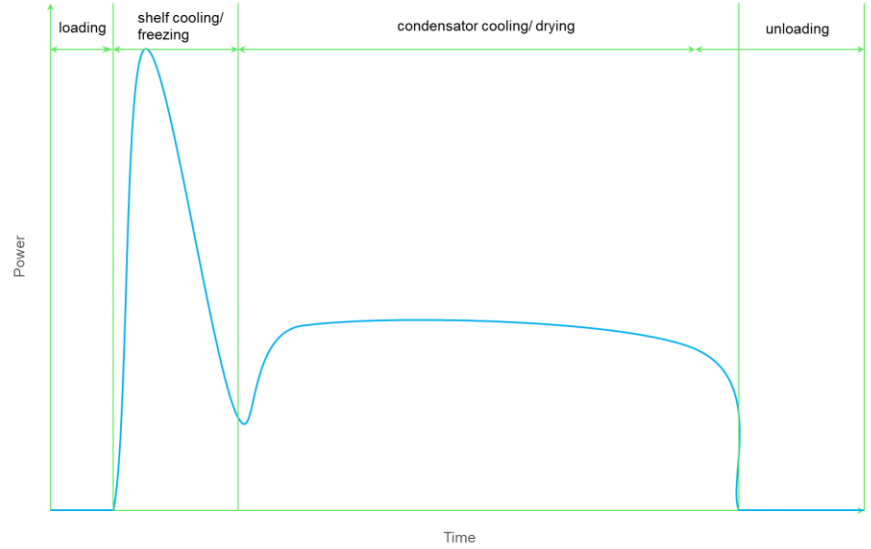




Lyophilization process from the view of refrigeration

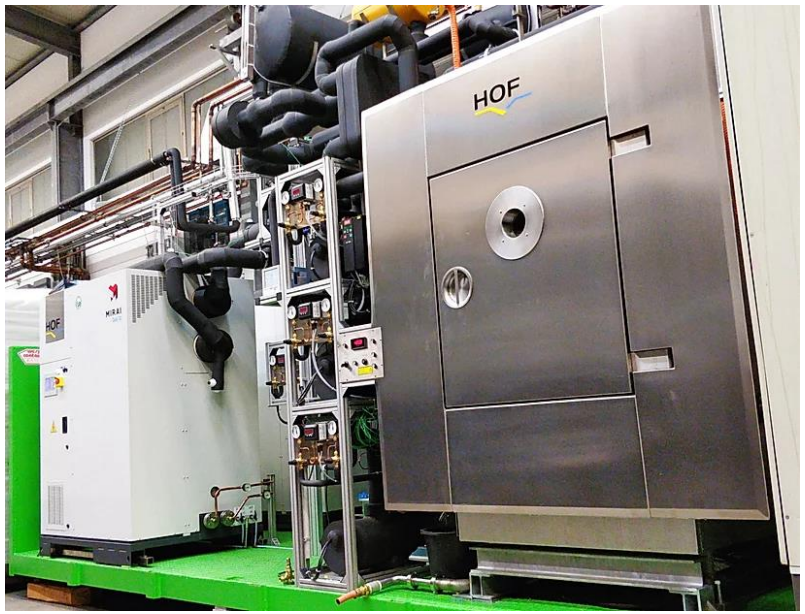


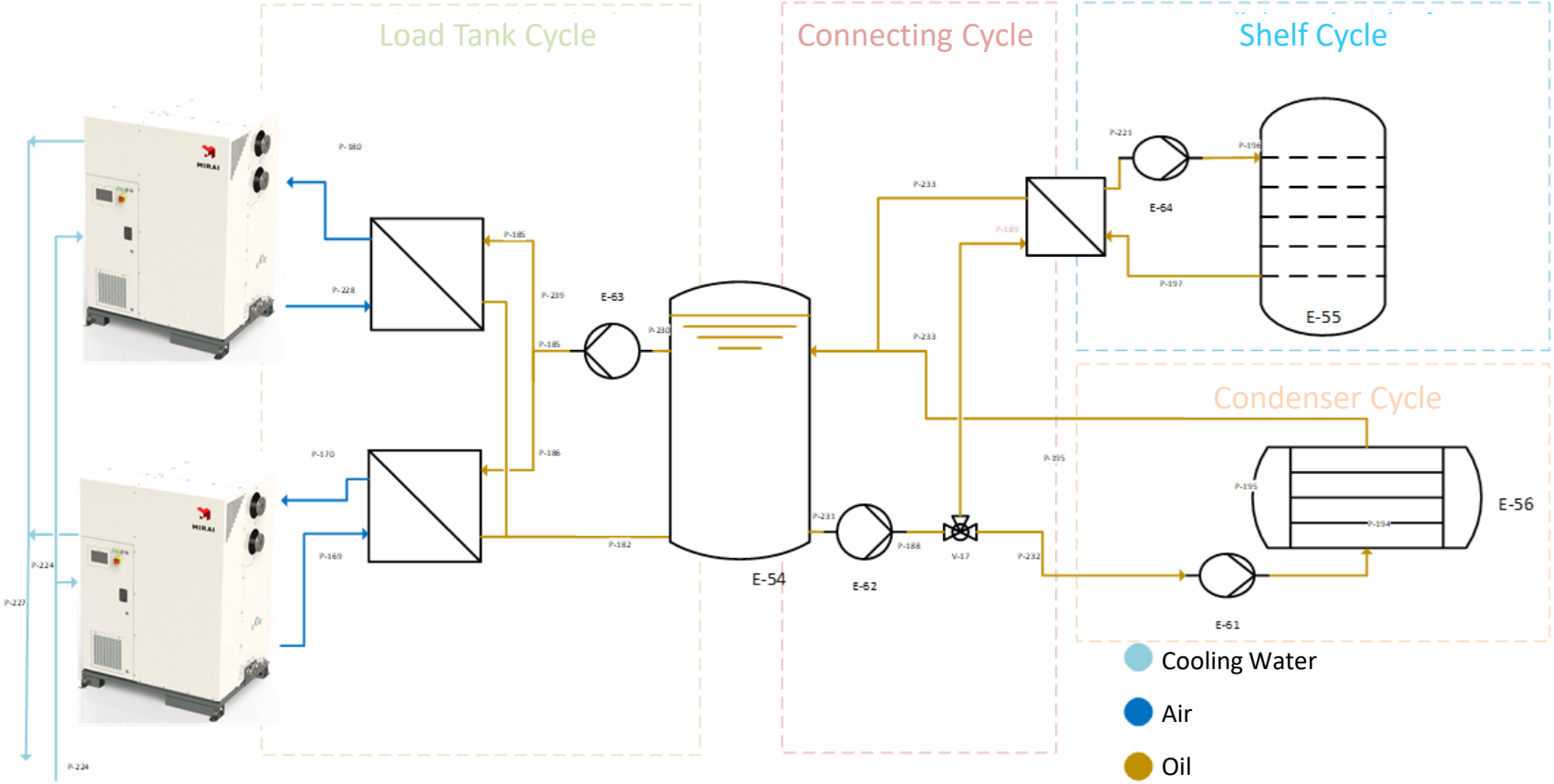




HOF-CryoBlizzard

Freeze dryer with air cycle refrigeration technology and load tank





Low temperature freezers

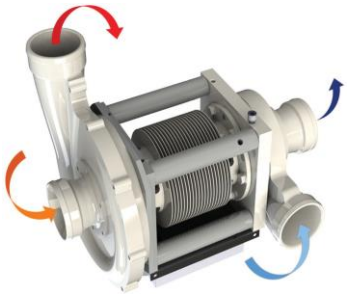
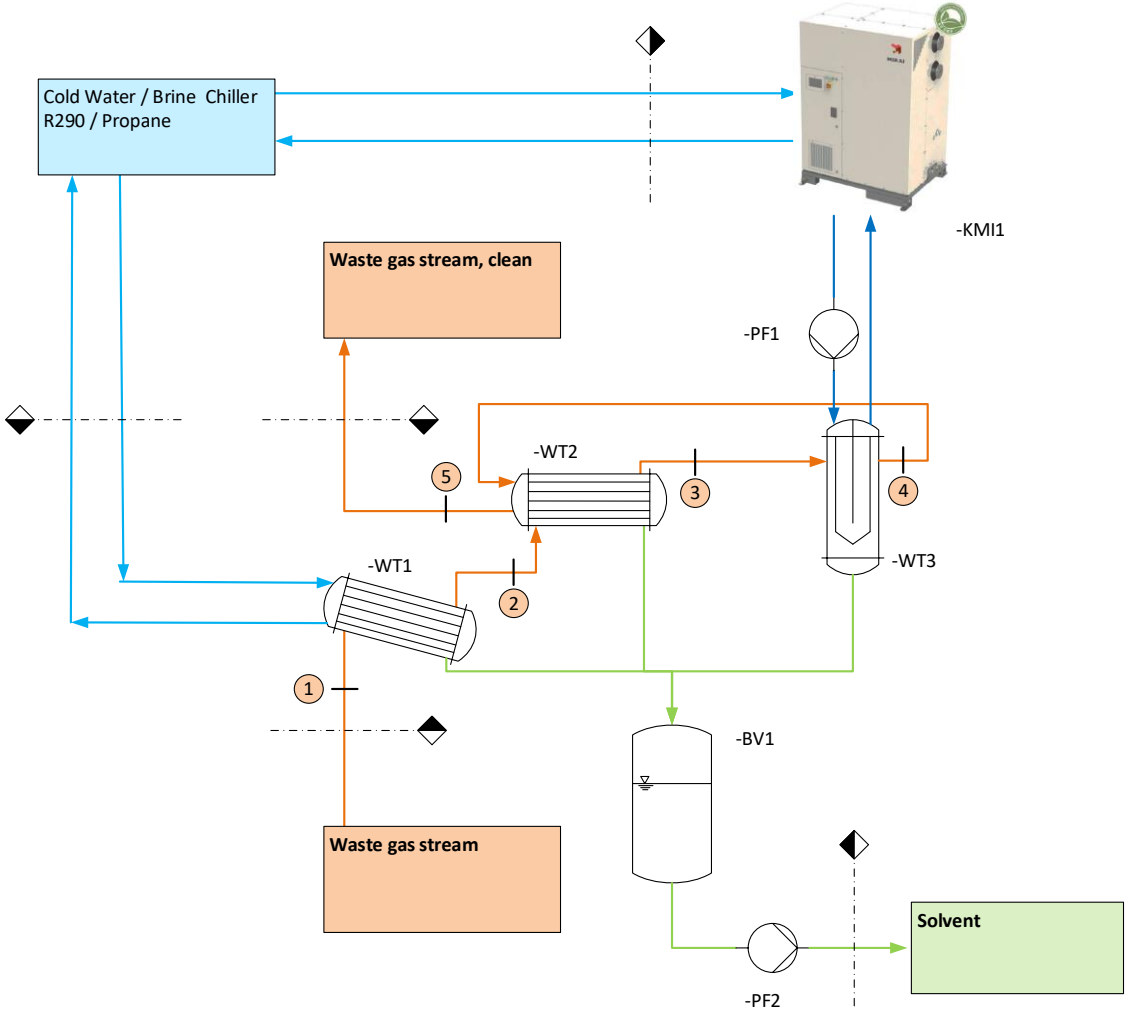


Plate freezing and thawing units (FTU):

Recovery of solvents out of exhaust gas flows

Process



THANK YOU

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