CREATIV

Refrigeration and heat pumping systems
Some result examples

Competence project for Reduced Energy use through Advanced Technology InnoVations

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130820 CREATIV Consortium Day

SP2 Electricity production from surplus heat

- *Improve cycle efficiency using natural working media*
- *Develop and test critical components*
- *Reduce capital costs by enabling compact systems*

SP3 Utilisation of thermal energy

- *Concepts for producing cold and heat from surplus heat*
- *Knowledge on heat and cold requirements in industry*
- *Solutions for LT heat utilisation within and among industries (clusters)*

SP4 Efficient heating and cooling

- *Refrigeration and heat pumping systems*
  - *Component and system design with natural refrigerants*
  - *Optimal system integration and control*
  - *Develop oil-free compressors & heat exchangers*

SP5 Education program

- *4 PhDs and 2 Researcher engagements*

CREATIV Lab

Lab investment by SINTEF ER supporting CREATIV research

Case studies | Case studies | Case studies

SP1 Technology innovation and exploitation of results

- *Innovation strategy*
- *Case coordination*
- *LCA*

Development of more energy efficient and benign refrigeration technology

- The climate challenge is demanding environmentally benign **working fluids** (CO_2, NH_3, HCs and H_2O)
- Efficient **components** are crucial for energy efficiency
  - Heat exchangers, compressors, expanders, ejectors

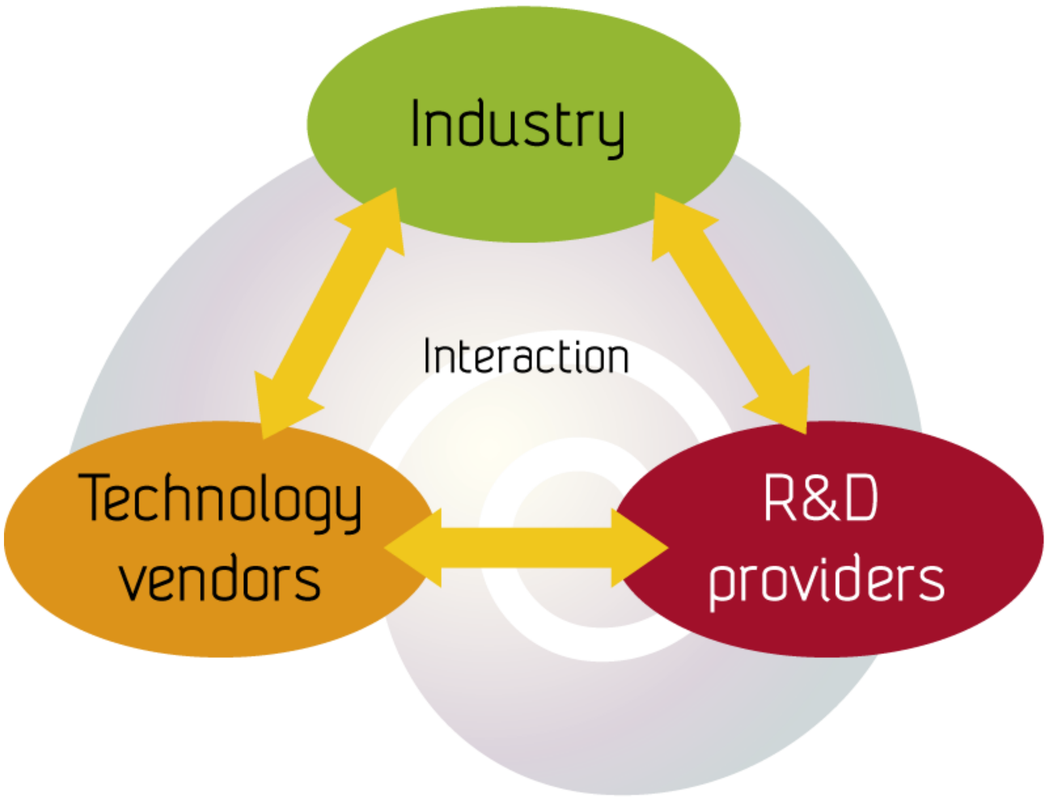
We need to reduce

emissions

- Development of improved **tools**, simulation models and test rigs, a necessary basis
- Development and implementation of improved **systems** for various application

Outline

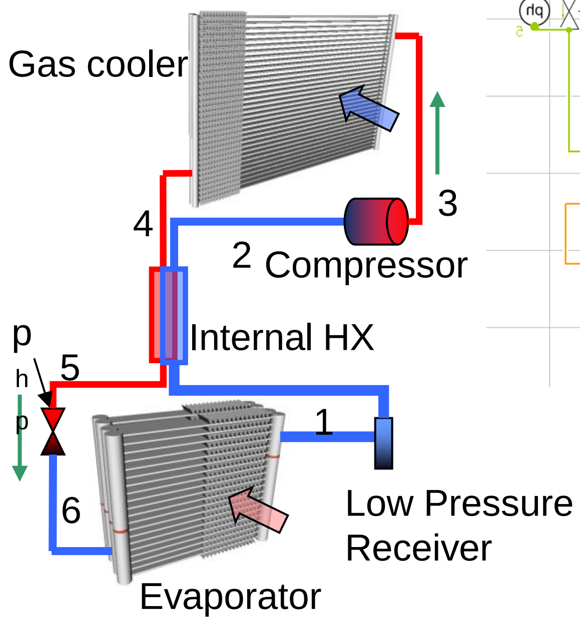
- Tool development
  - Modelling
    - Stationary and Dynamic
    - Component and system
  - Laboratory infrastructure
    - Compressor and hx test rig
- Component development
  - Compressors
    - Reciprocating
    - Turbo
  - Ejectors
  - Heat exchangers
- Applications
  - Supermarket
  - Space conditioning
  - RSW (refrigerated sea water)



Improved simulation models

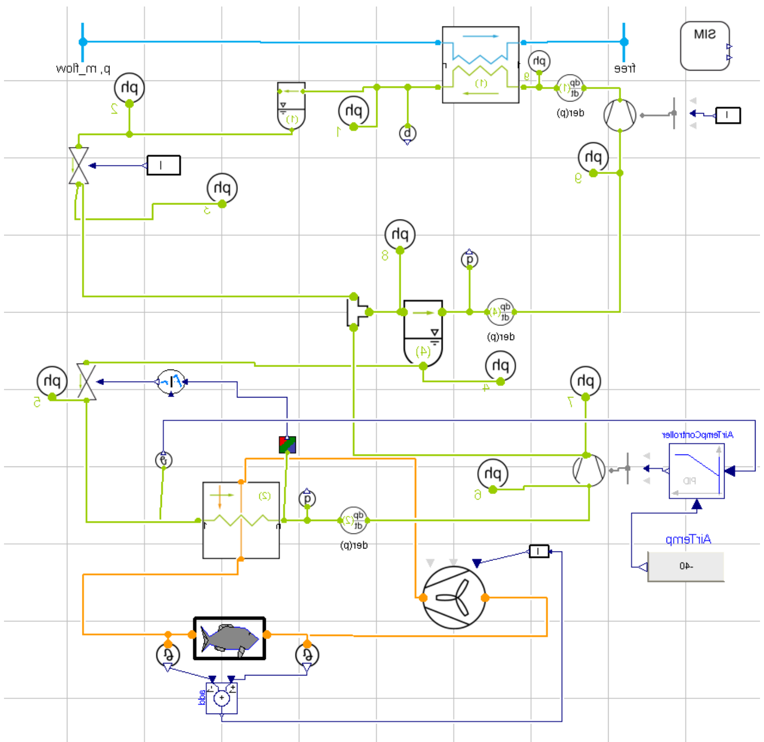
Enabling energy efficient design

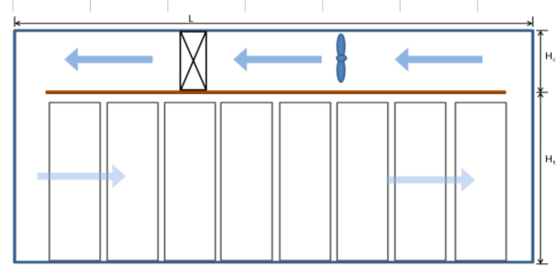
- **Systems**
  - **Refrigeration systems**
  - **Processes**
  - **Simulation and optimisation**
- **Components**
  - **Heat exch**
  - **Compressors**
  - **Ejectors**
- **Stationary and dynamic**



System sim with detailed component models, stationary

Reference: Skaugen et al 2010



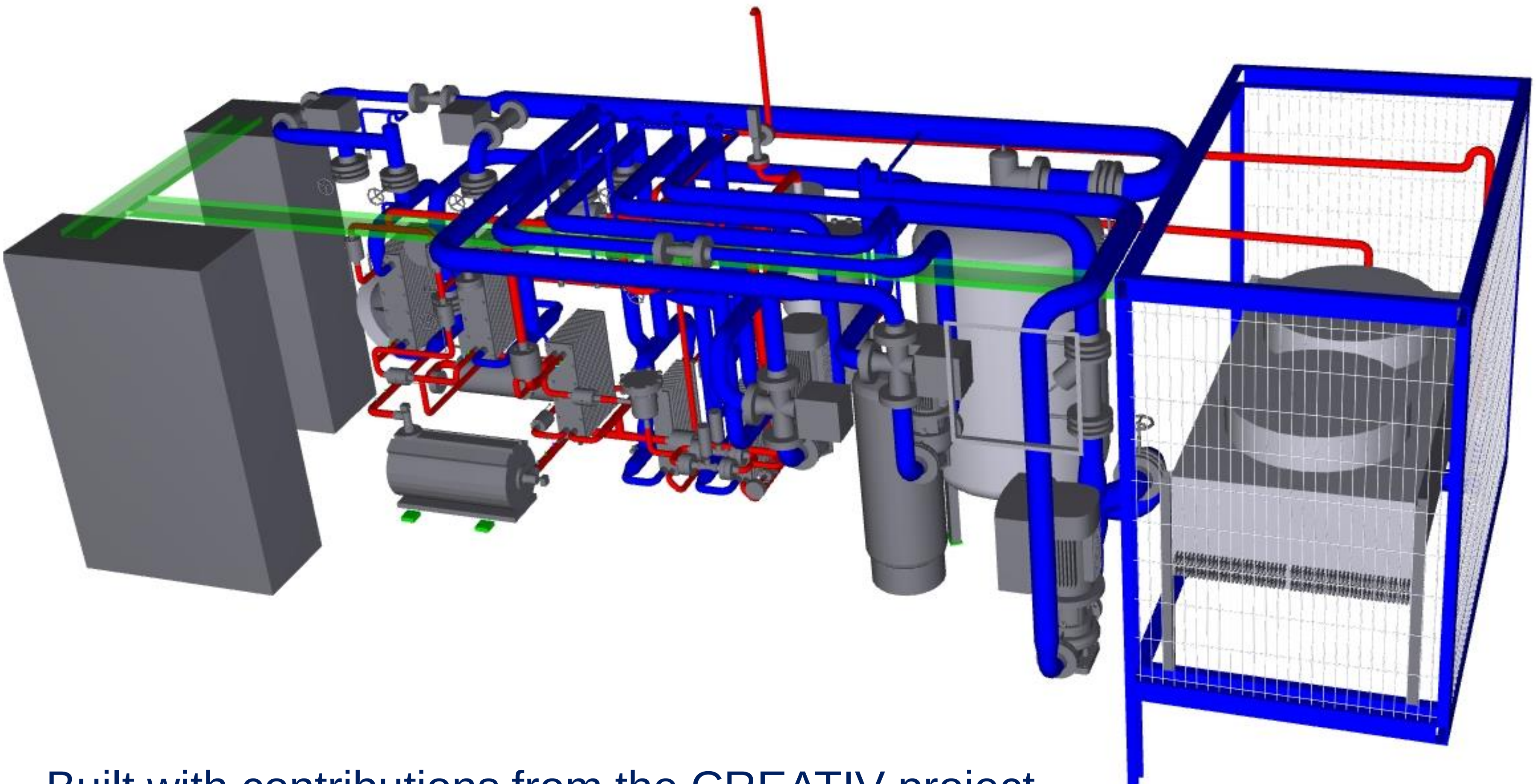


Dynamic model for freezing tunnel and refrigeration system

Reference: Andresen et al 2011

Improved laboratory infrastructure

R744 Compressor and Component Test Facility @ SINTEF

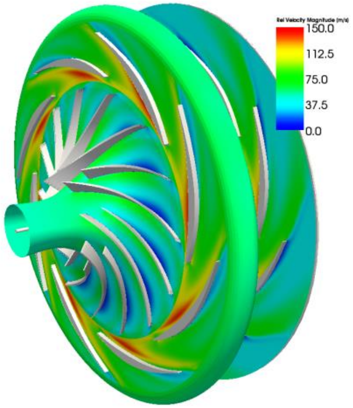


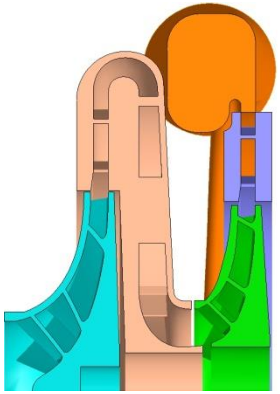
Built with contributions from the CREATIV project

Component development

Efficient components are the building blocks

- **Compressors**
  - **Reciprocating compr**
  - **Turbo compressor**
    - **Oil free technology**
- **Ejectors**
- **Heat exchangers**
  - **HP plate heat exch**
  - **Sublimator**



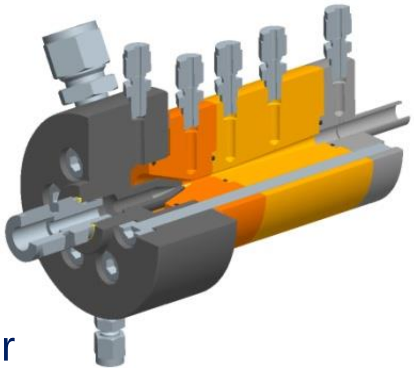


CO_2 turbo compressor

Reference: Hafner et al 2011

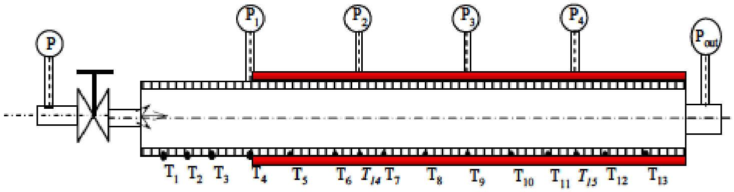
CO_2 plate hx, 140 bar

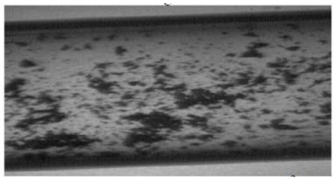
Reference: Kaori, r744.com



CO_2 ejector

Reference: Neksa et al 2010





CO_2 SVE hx

Reference: Niu et al 2010

Components:

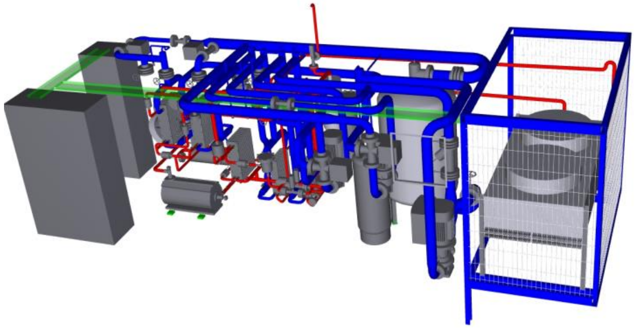
RECIPROCATING COMPRESSORS COOPERATION OBRIST E AND SINTEF

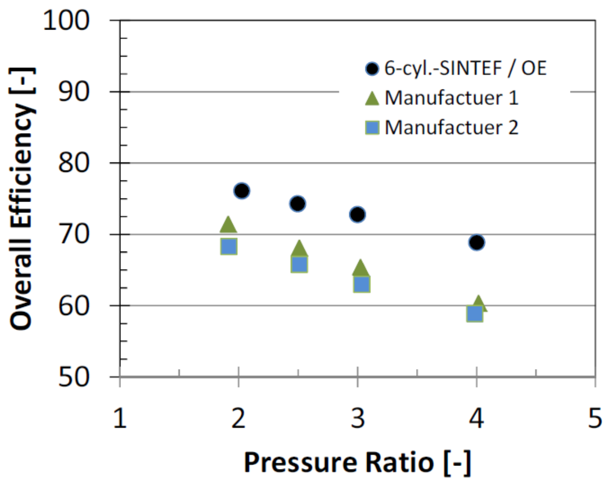
Glimpse

Compressor development

CO_2 compressor and test rig

- **5-12 % improved energetic efficiency**

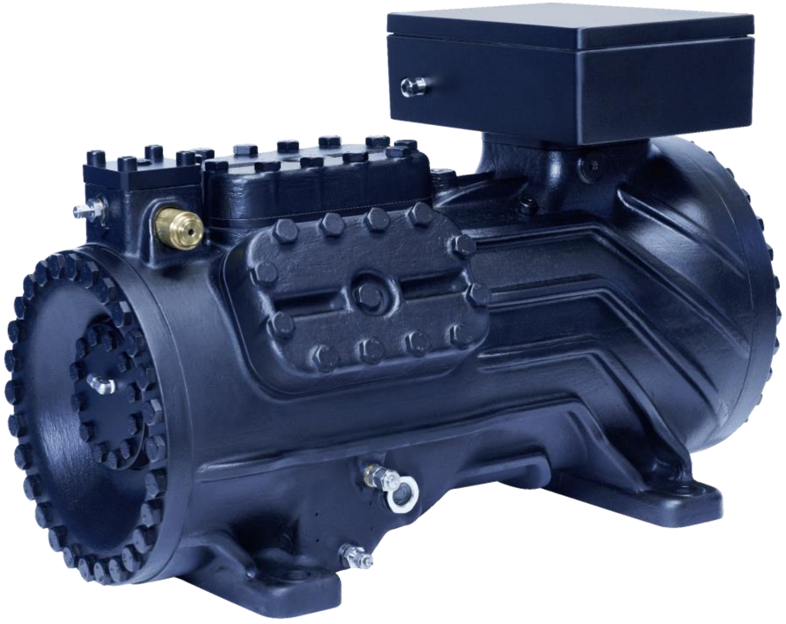




Joint development project between SINTEF and OE

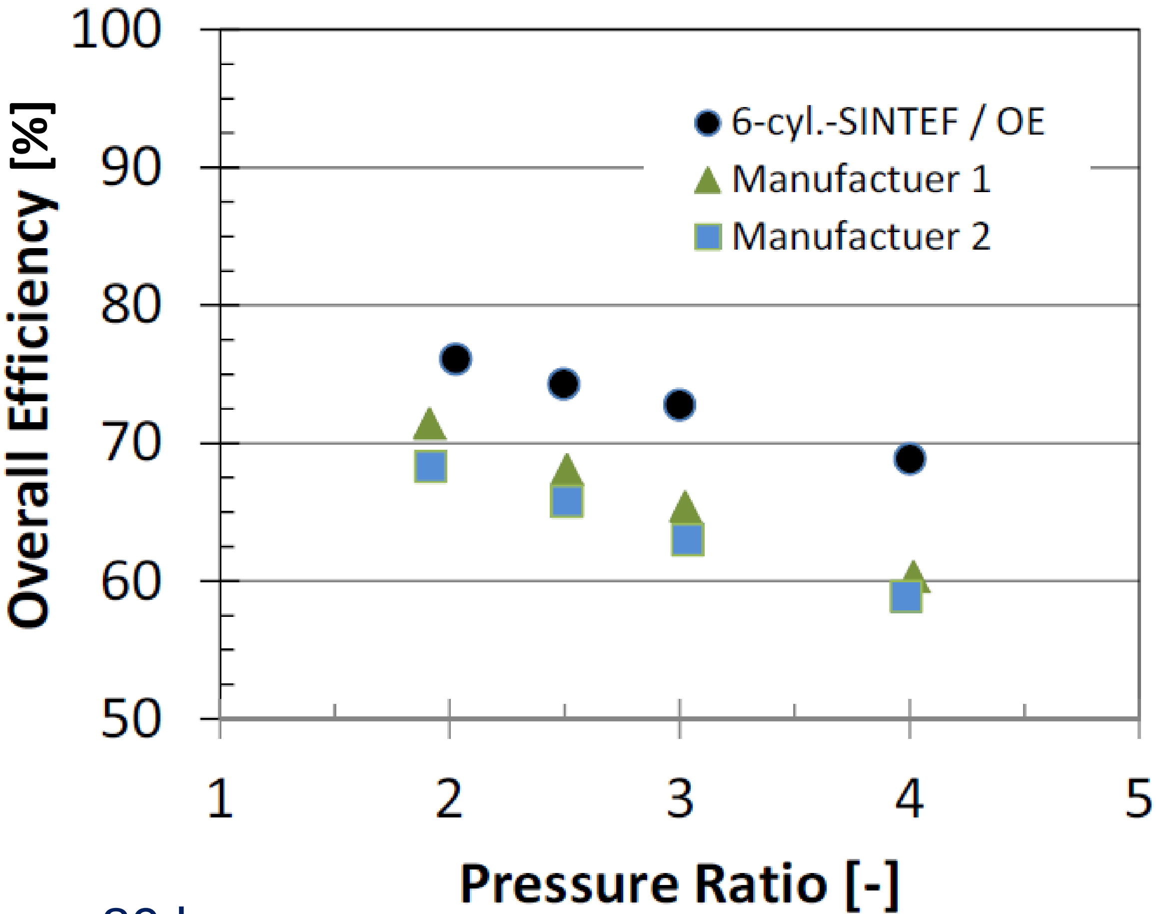
18-90m³/h R744 compressor [2012]

Suitable for e.g. commercial refrigeration applications



	technische Daten
Höhe x Breite x Länge [mm]	**500 x 440 x 830**
Gewicht [kg]	**286**
Volumenstrom [m³/h]	**18 - 90**
Hubraum [cm³]	**380**
Max. el. Leistungsaufnahme [kW]	**100**
Drehzahl [min^{-1}]	**800 – 4 000**
Frequenzbereich [Hz]	**53 - 267**

18-90m³/h R744 compressor [2012]



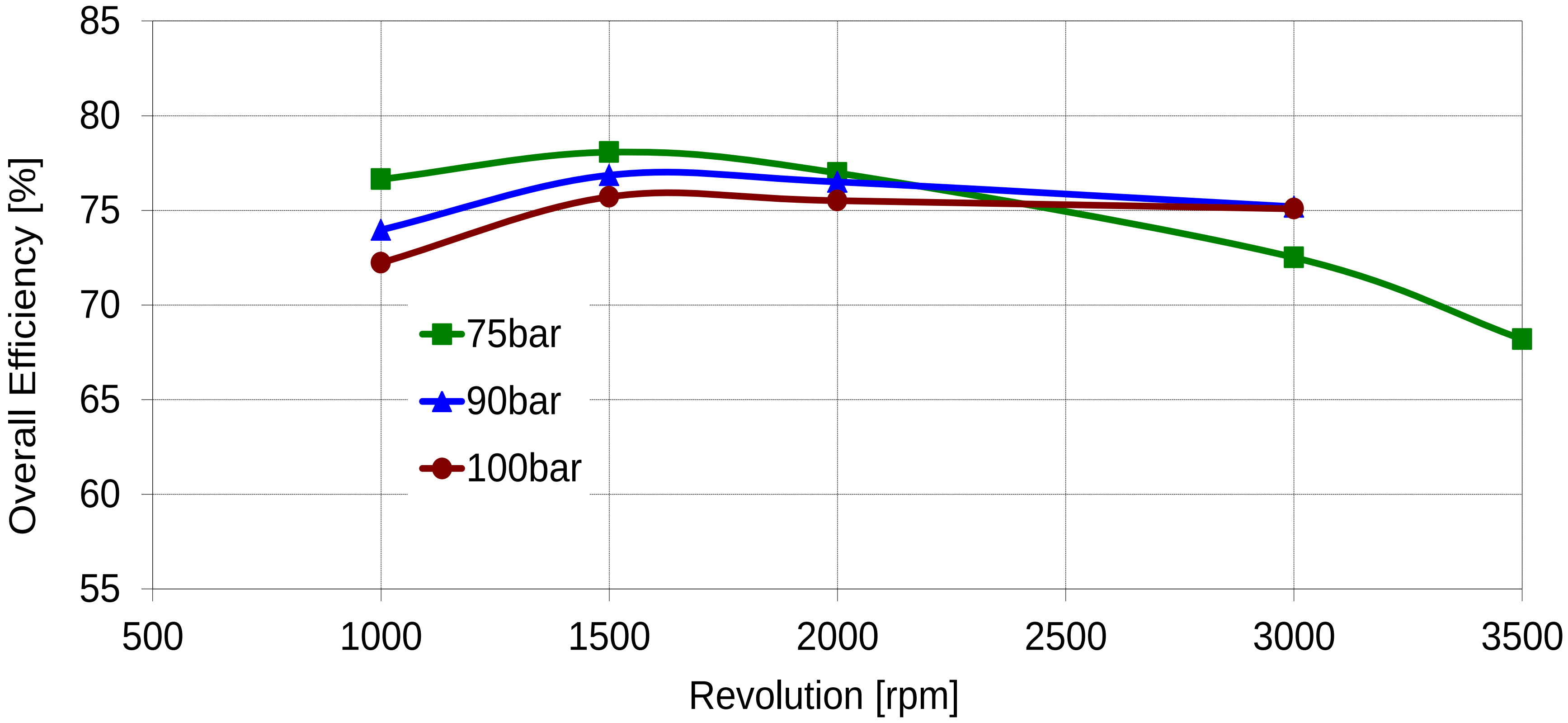
1500 rpm

discharge pressure: 80 bar

superheat at the compressor inlet: 10 K

18-90m³/h R744 compressor [2013]

Overall efficiency at varying speed, p_0=35 bara



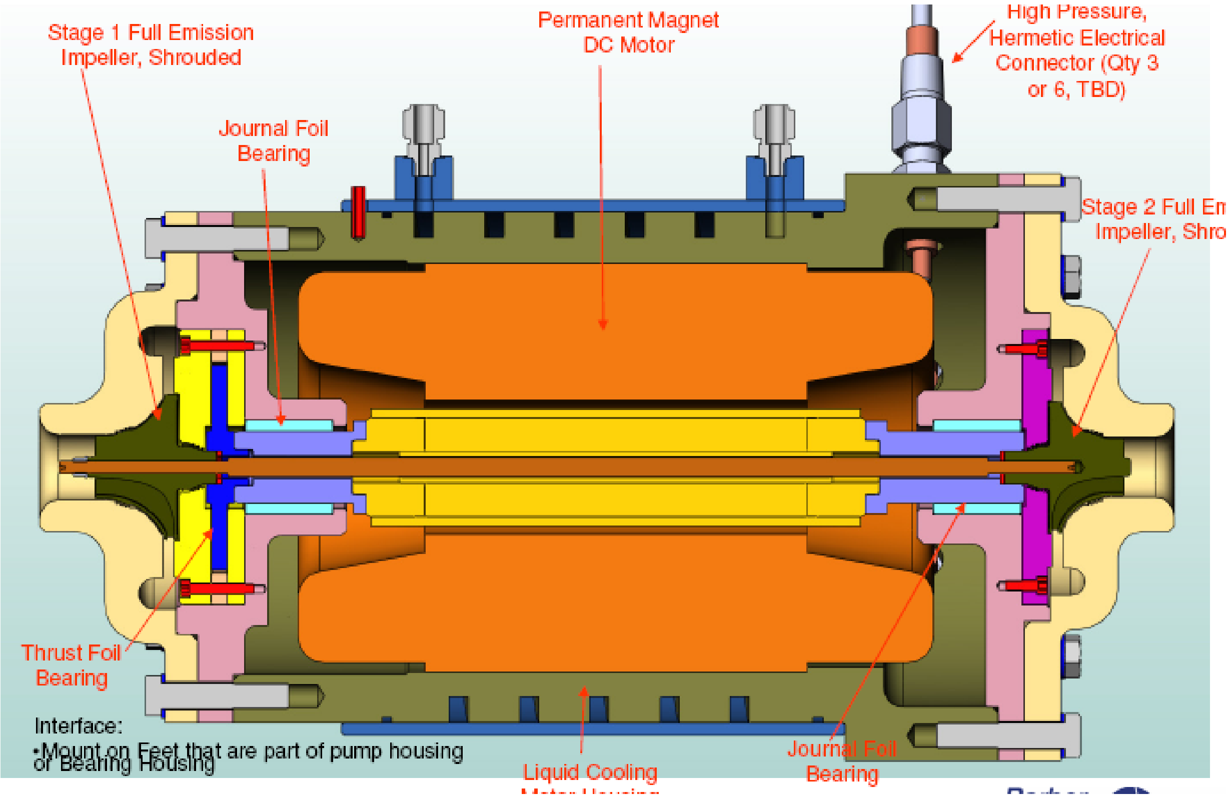
Industry Energy Efficiency CREATIV

Components:

TURBO COMPRESSORS
PHD STUDENT BARTOZS KUS ET AL

Base case turbo concept for CO_2

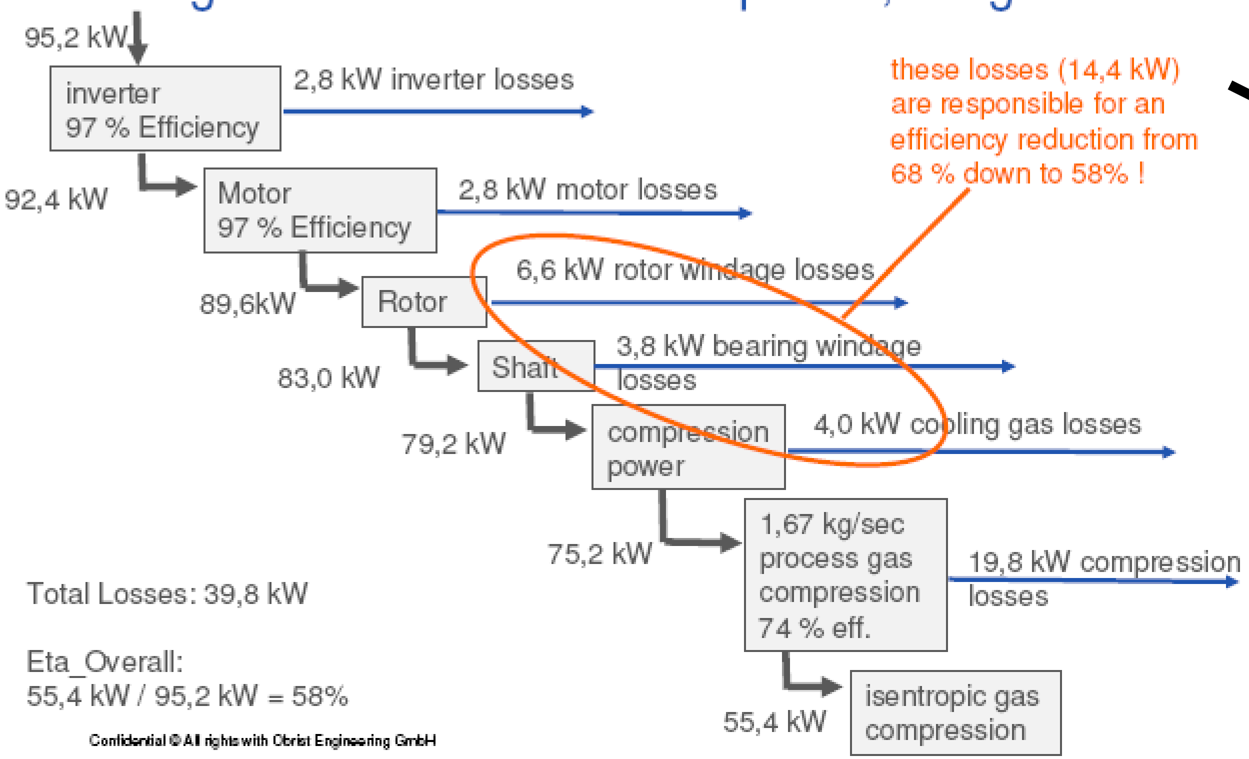
- Ship cooling
- Mass flow 1.6
- Pressure ratio: 2.13
- Pressure ratio **per stage: 1.46**
- Gas bearings
- Aero efficiency: 75%
- Total efficiency: 60%



Loss analysis base case

OBRIST
ENGINEERING

Design Point: 30/64bar - 47krpm - 1,67 kg/sec



What if we can get rid off these non-compression losses associated with high speed, but **maintain 75% efficiency on the impeller side**

Efficiency curves

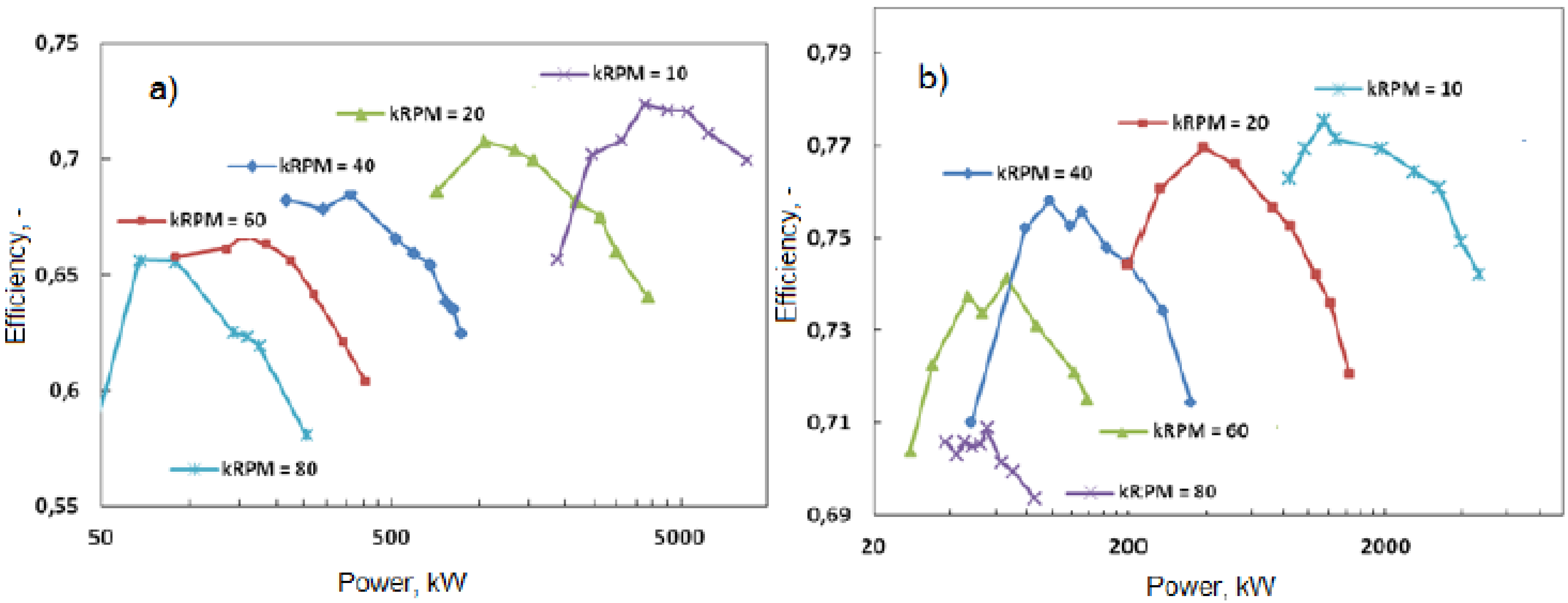
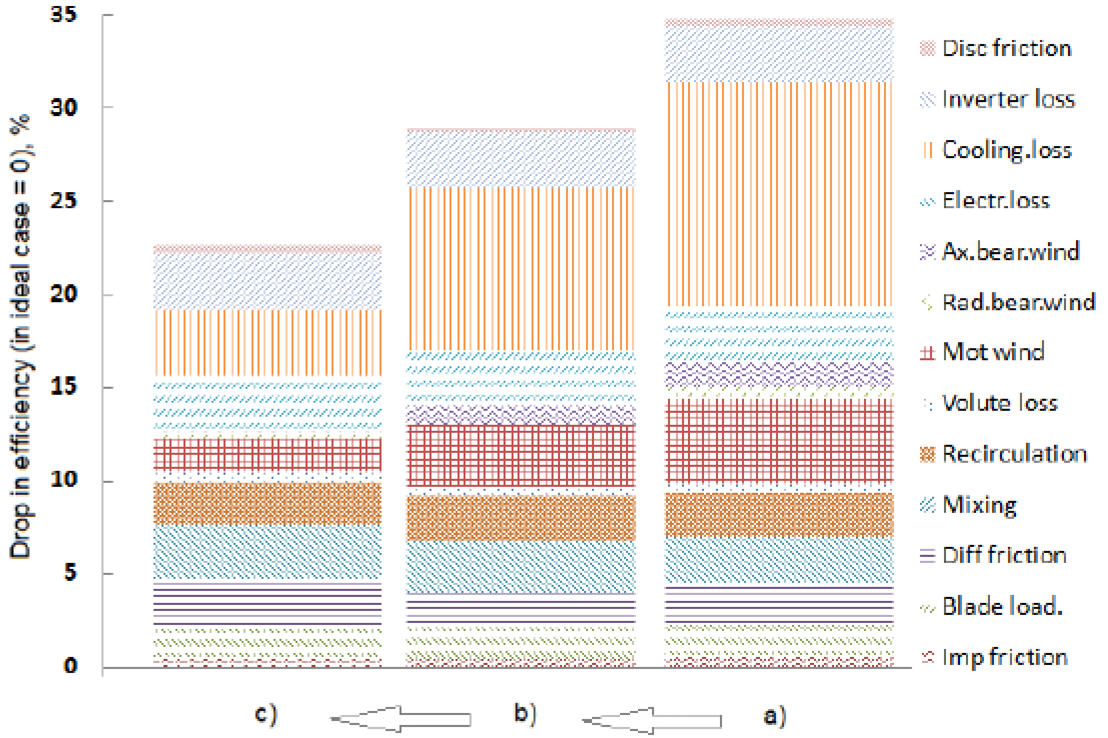


Figure 2. 2-stage (a) and 4-stage (b) compression efficiency for low stage loop in cascade refrigeration system.

Loss distribution

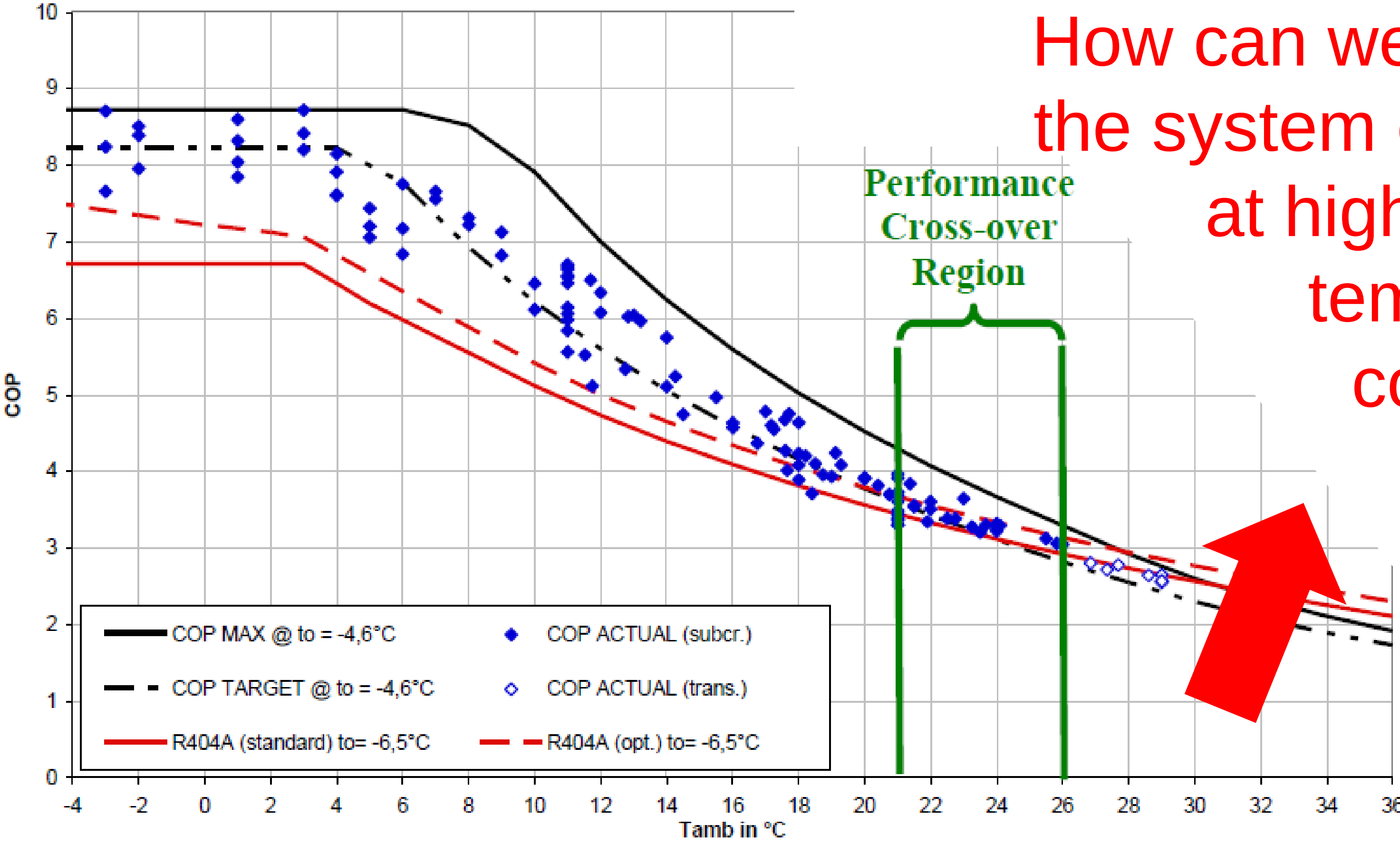


a) Single 2-stage compressor, 80 krpm, 84 kW
b) Single 2-stage compressor, 20krpm, 1333 kW
c) Two 2-stage machines in series, 40 krpm, 98 kW in total

Components:

EJECTORS

Standard R744 Booster system for commercial refrigeration



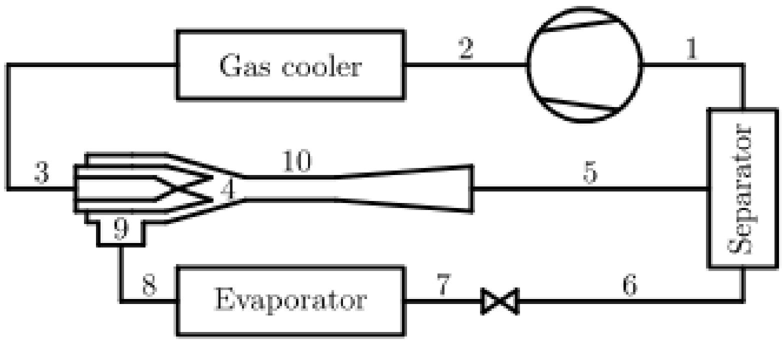
Challenge:
How can we improve the system efficiency at high ambient temperature conditions?

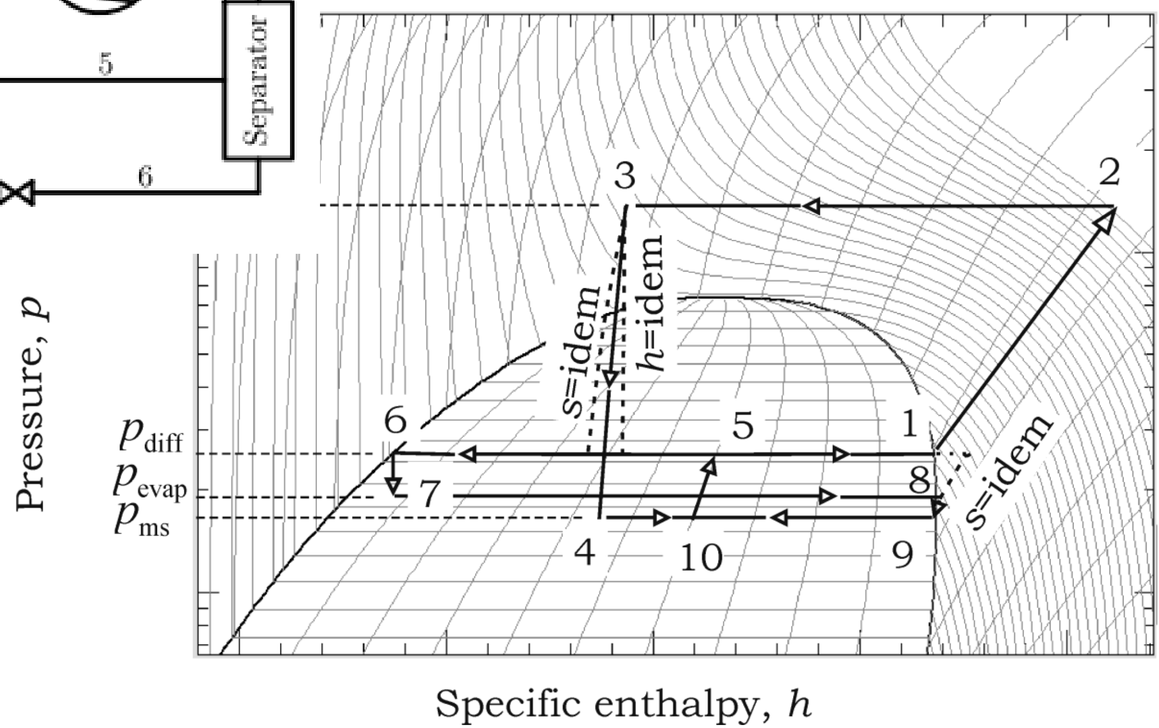
Ref. Carrier, ICR2011 Prag

One possible way:

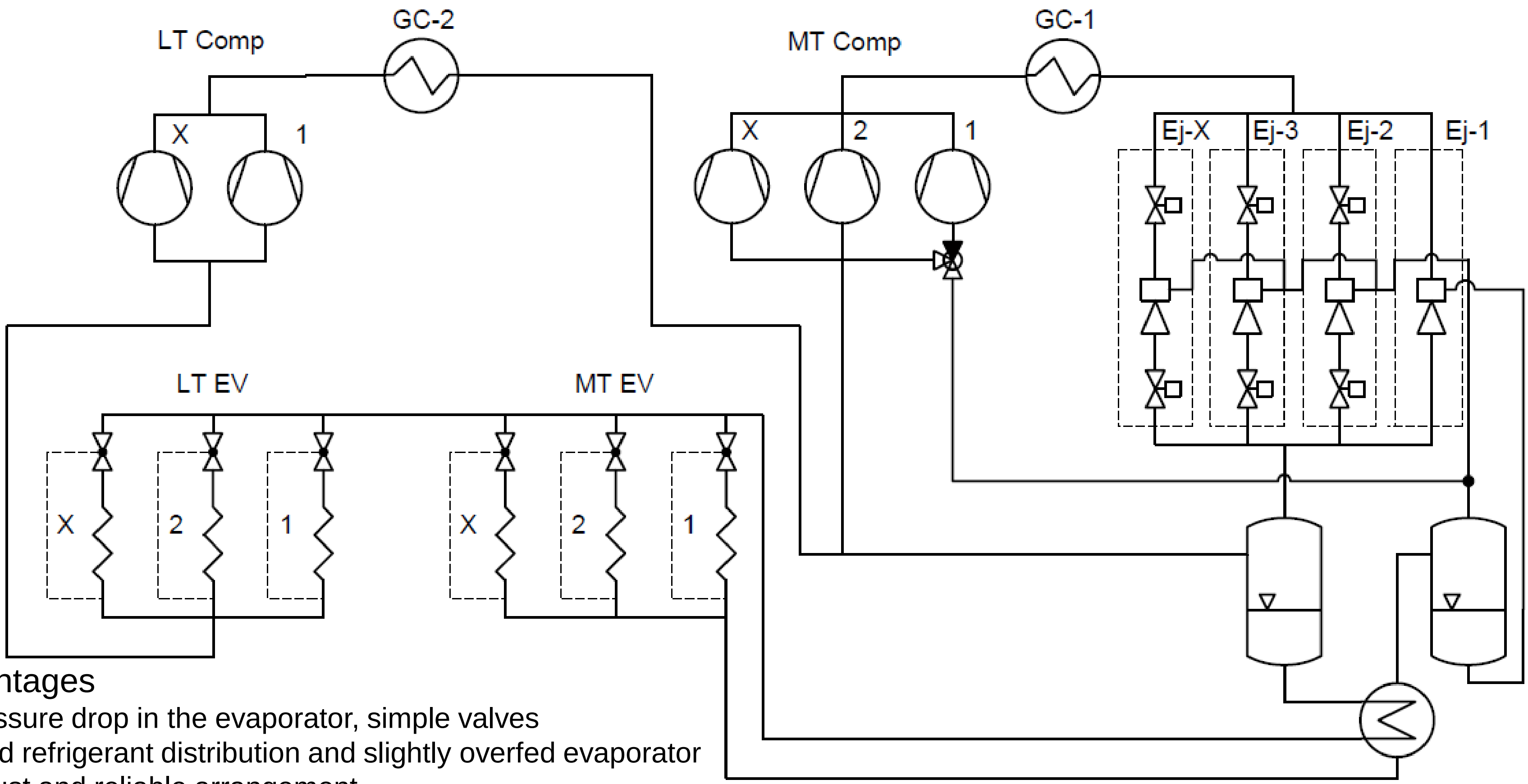
Transcritical R744 refrigeration cycle

Using a two-phase ejector for expansion work recovery and the corresponding pressure-specific enthalpy diagram





Proposal for next generation of R744 commercial refrigeration system



Advantages

- pressure drop in the evaporator, simple valves
- good refrigerant distribution and slightly overfed evaporator
- robust and reliable arrangement
- lubricant management in separator

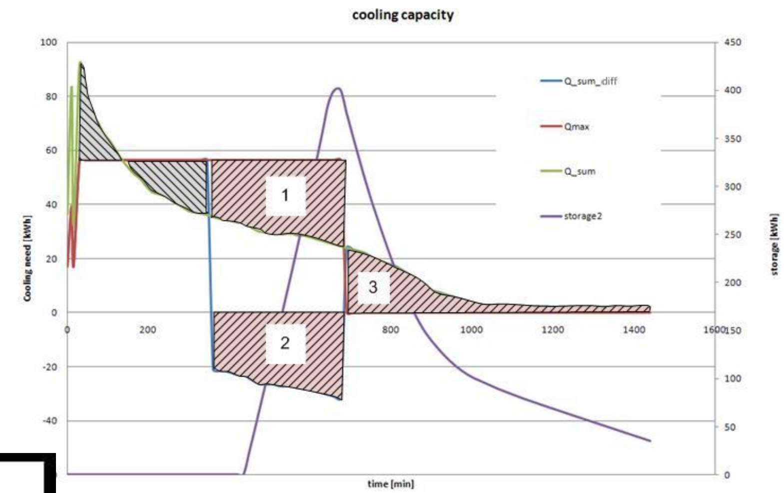
Components:

SOLID CO_2 SUBLIMATOR
NIU ET AL

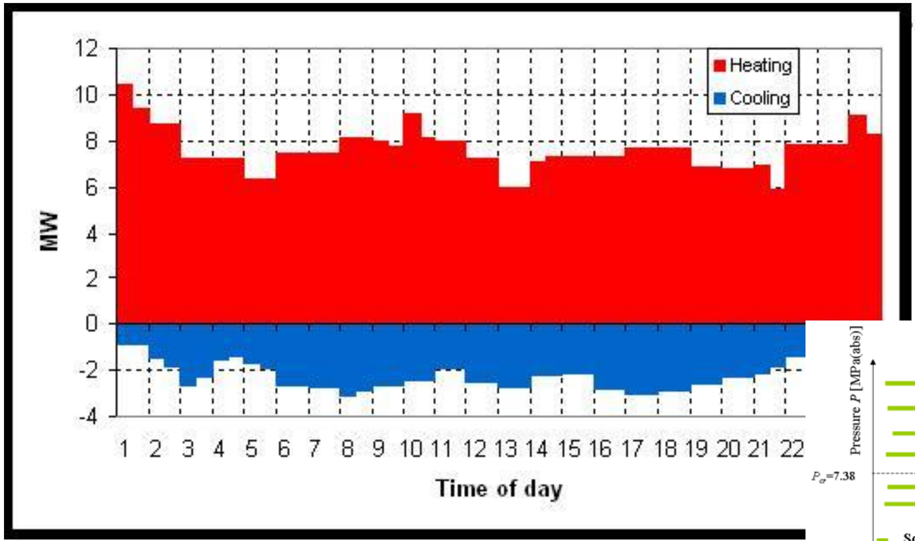
Energy efficiency

Heat and cold accumulation

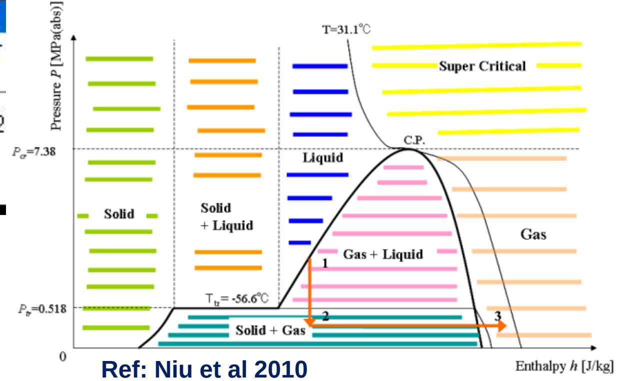
- **CO_2 for low temperature cold accumulation**



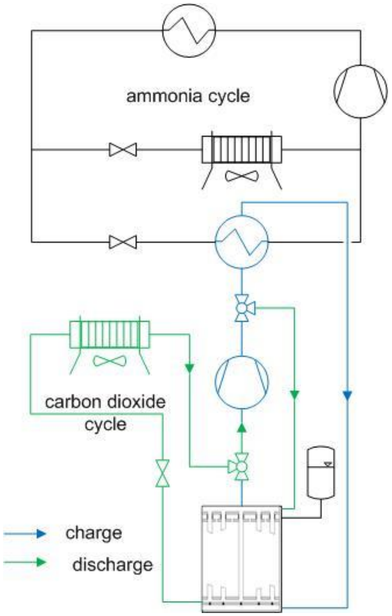
Ref: Hafner et al 2011



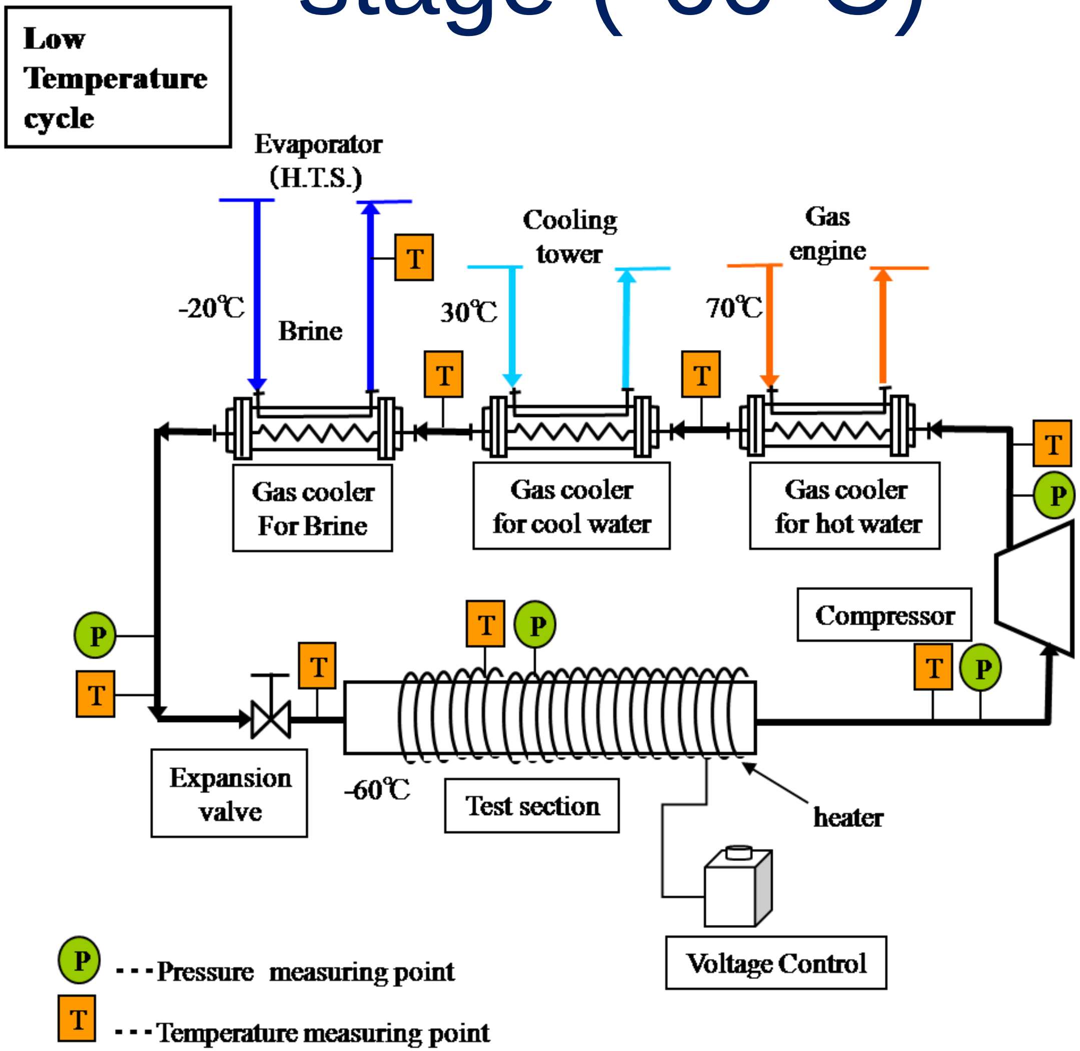
Ref: Nordtvedt et al 2011



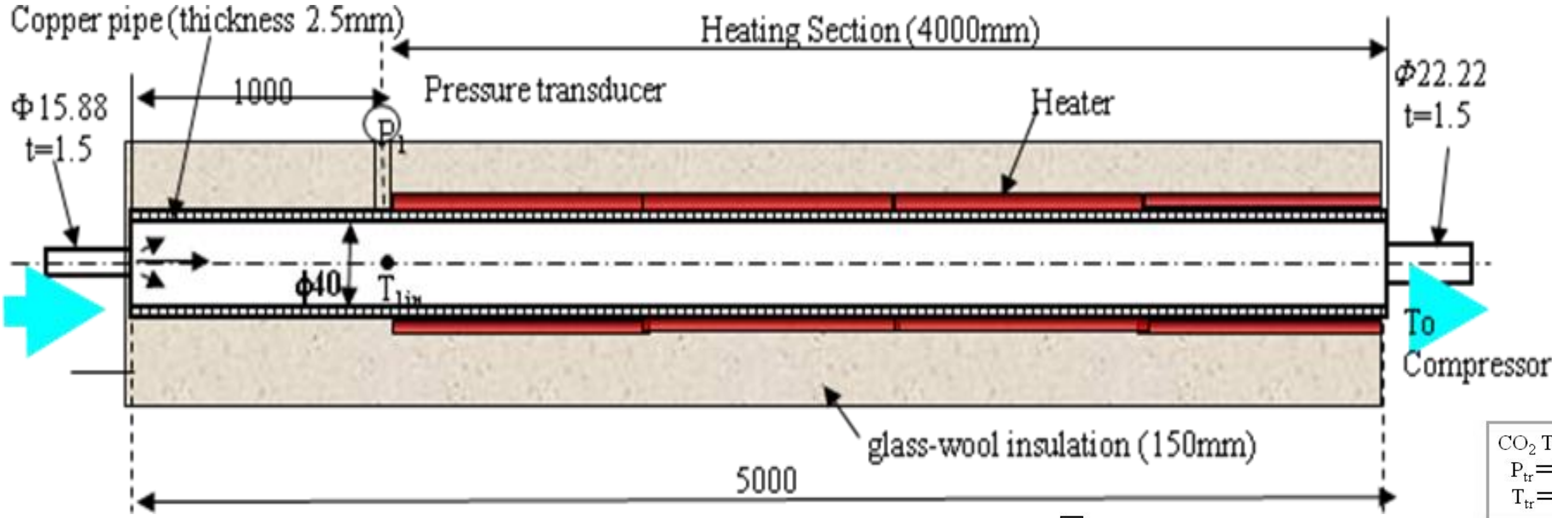
Ref: Niu et al 2010



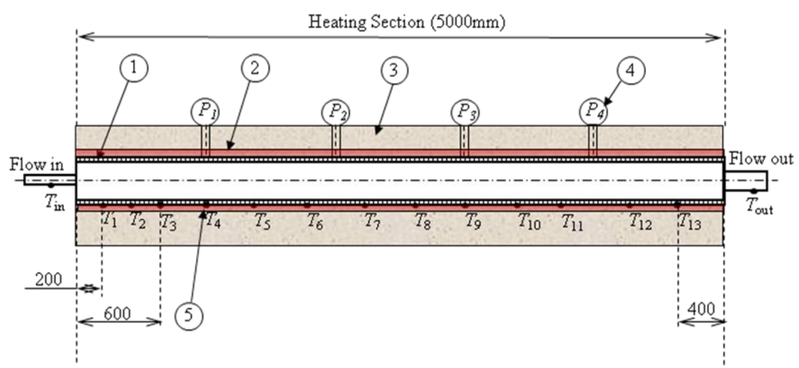
Schematic of low temperature stage (-60^oC)



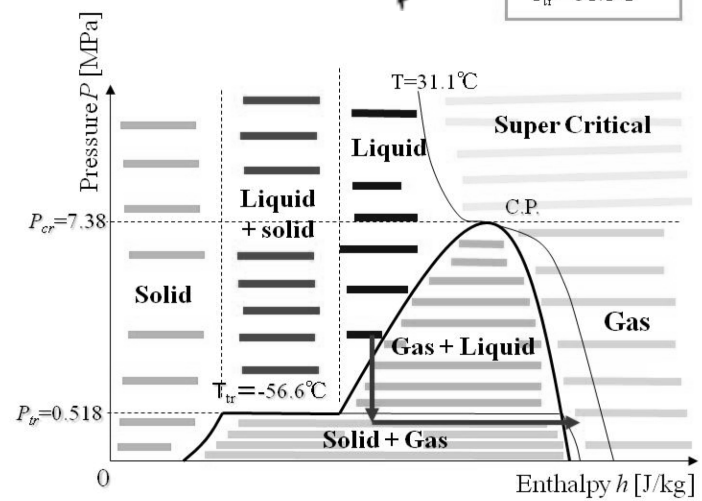
Test section and operation



CO_2 Triple Point
P_{tr}=7.38MPa
T_{tr}=31.1℃

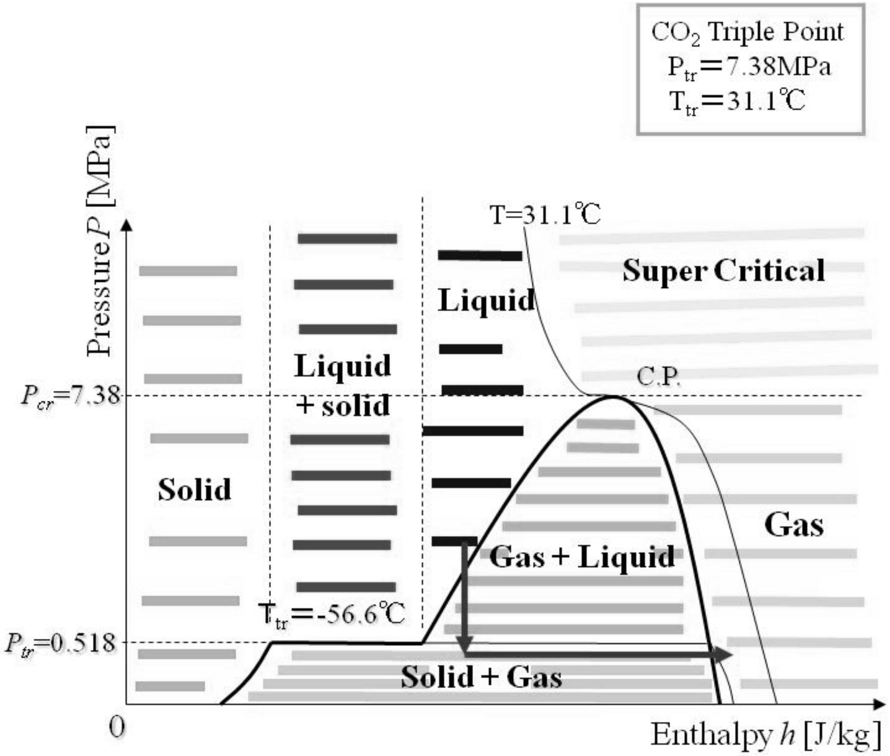


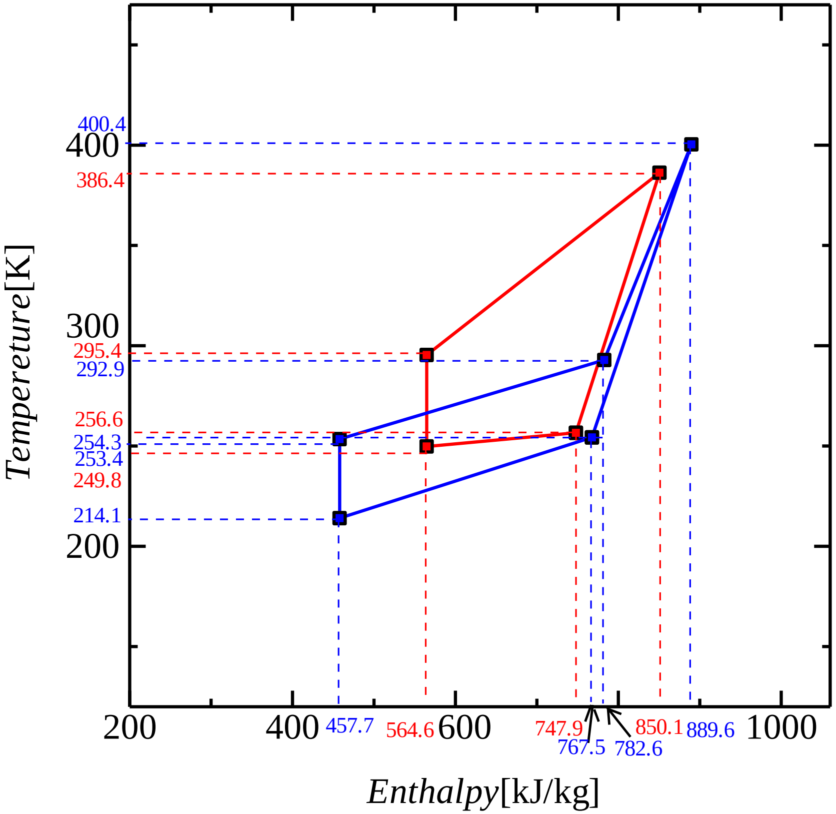
① Copper pipe (d=40mm, t=2.5mm, L=5000mm)
② Heater (silicon rubber)
③ Glass-wool insulation (150mm)
④ Pressure transducer (4 points, uniformly distributing along test section)
⑤ Thermocouple (15 points)



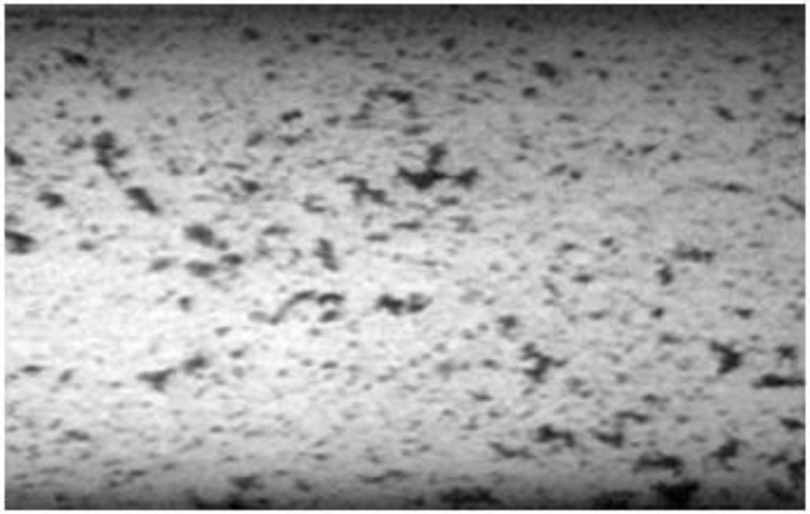
Throttling from liquid to solid-vapour state
Sublimation of CO_2 dry ice to gas

Cycle operation

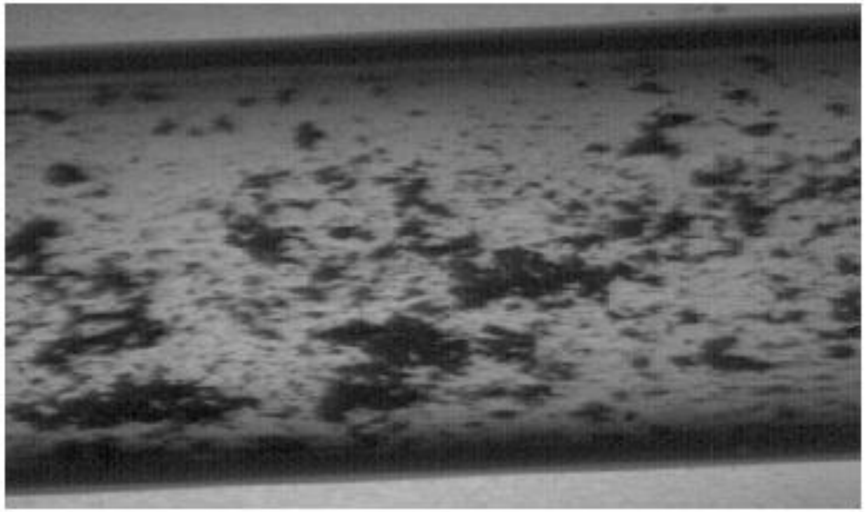




Visualisation



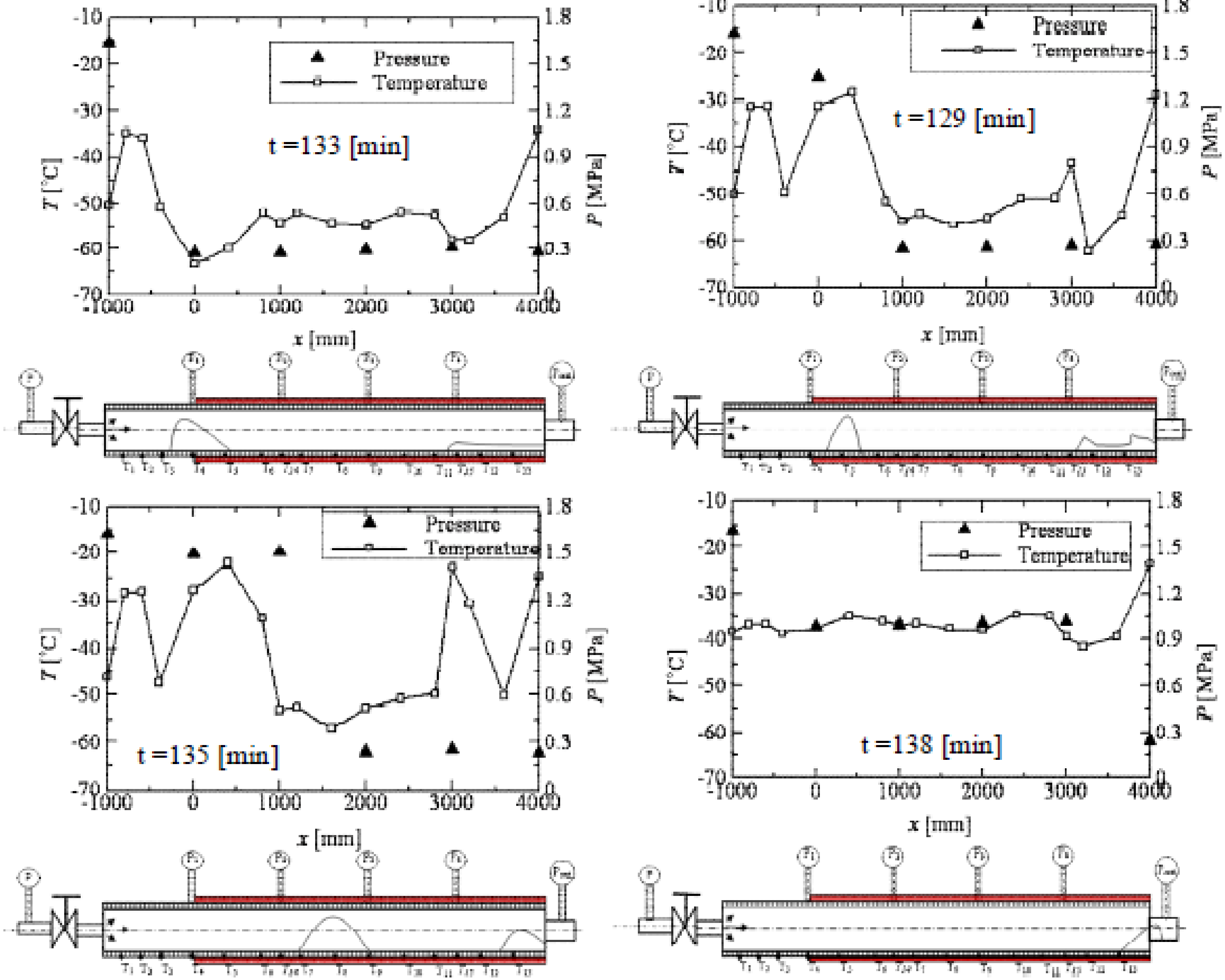
(a) CO_2 solid-gas flow at opening conditions of 15mm of expansion valve



(b) CO_2 solid-gas flow at at opening conditions of 10mm of expansion valve

Sedimentation

Variations of local pressure and wall temperature with the dry ice sedimentation inside
the test section at different times



Case:

SUPERMARKET ENERGY SYSTEMS

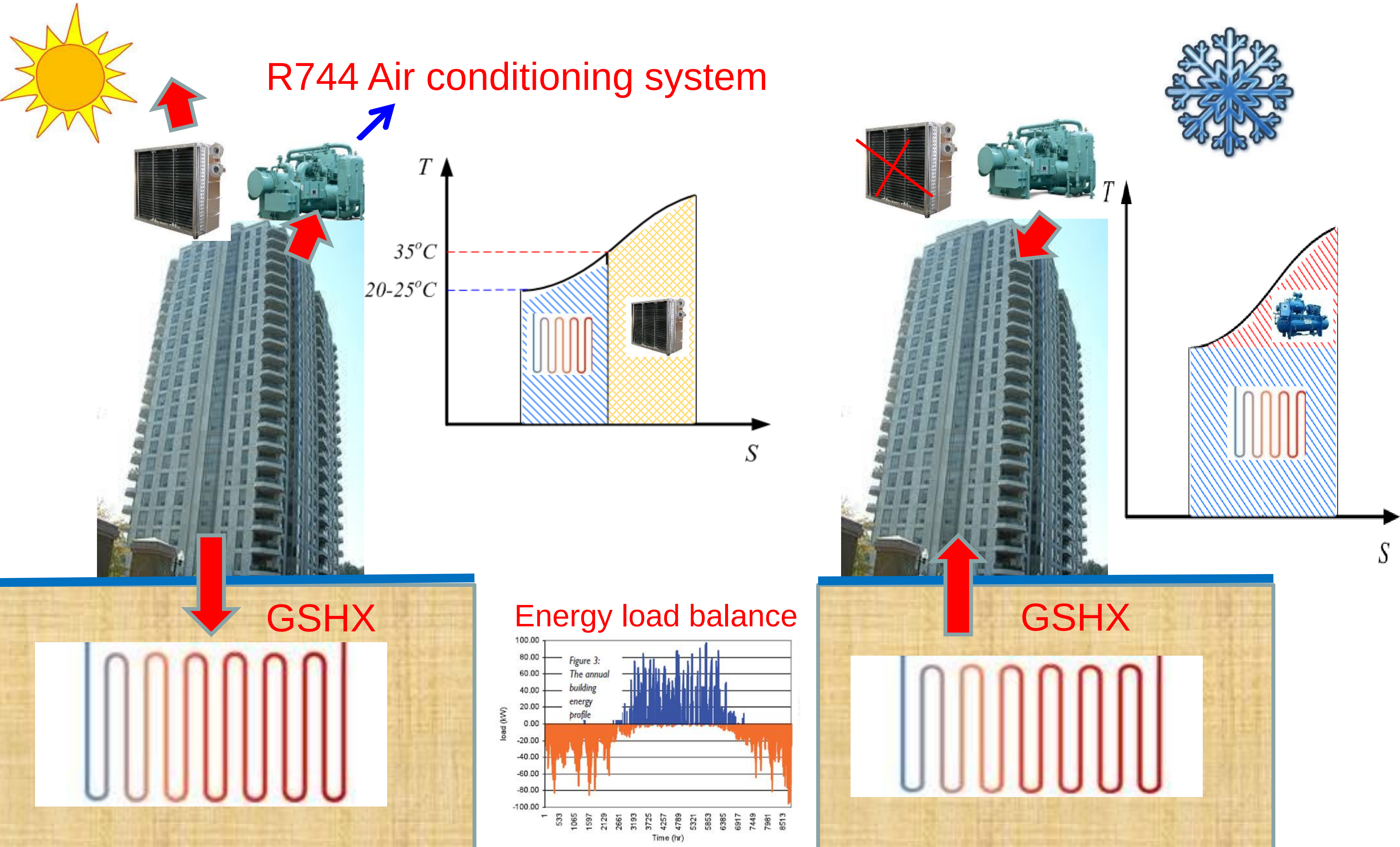
PRESENTED BY ARMIN HAFNER IN THE NEXT PRESENTATION

Case:

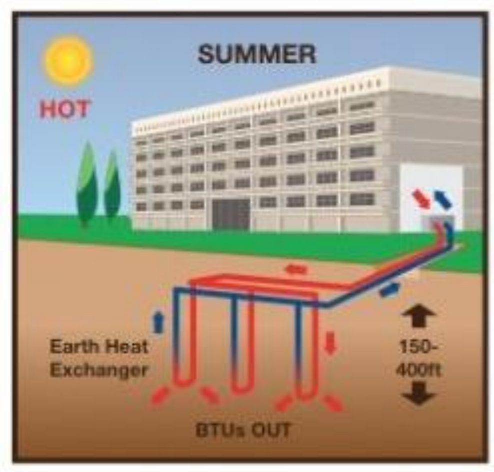
HEAT PUMPS FOR SPACE CONDITIONING

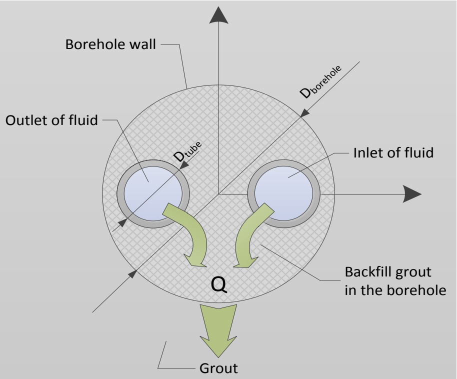
POSTDOC HAITAO HU ET AL

1. Motivation

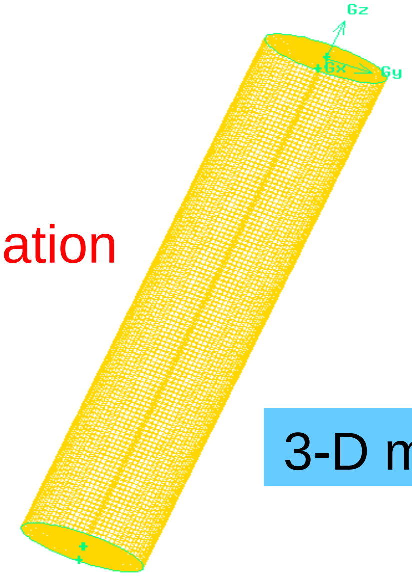


2. CFD simulation on performance of GSHX





CFD simulation

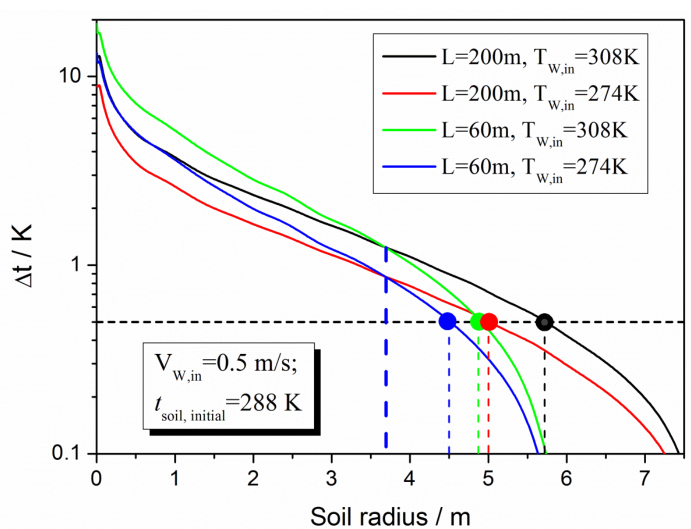


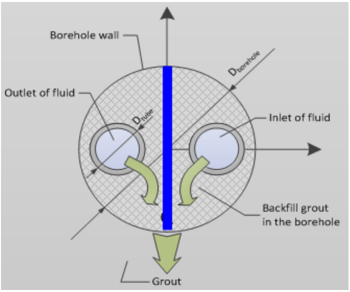
3-D model

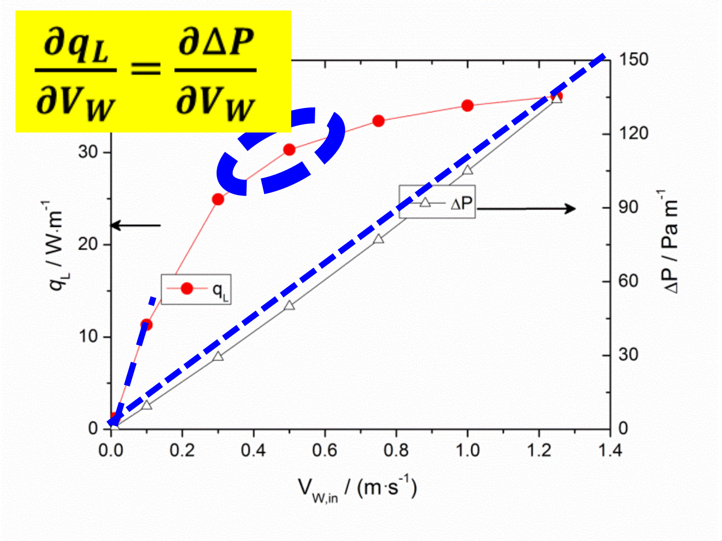
Influence factors
HX length (m);
Fluid inlet temperature (K); Fluid inlet velocity (m/s)
Initial soil temperature (K); Soil types for different areas
Backfill material (Water, air, different soils)

3. CFD simulation on performance of GSHX (Results)

- ✓ **Distance between HXs should be 9~12 m;**
- ✓ **$q_{200} \approx 0.9\, q_{60}$ (W/m); $Q_{200} \approx 3.0\, Q_{60}$ (W);**
- ✓ **Adding insulation board enhances heat flux by 10%;**
- ✓ **Optimal backfill material (α=2.0~3.0 E-6 m^2/s);**
- ✓ **The optimal fluid velocity is 0.5~0.7 m/s.**







Systems:

CO_2 RSW (REFRIGERATED SEA WATER)
LADAM ET AL (2012)

Glimpse

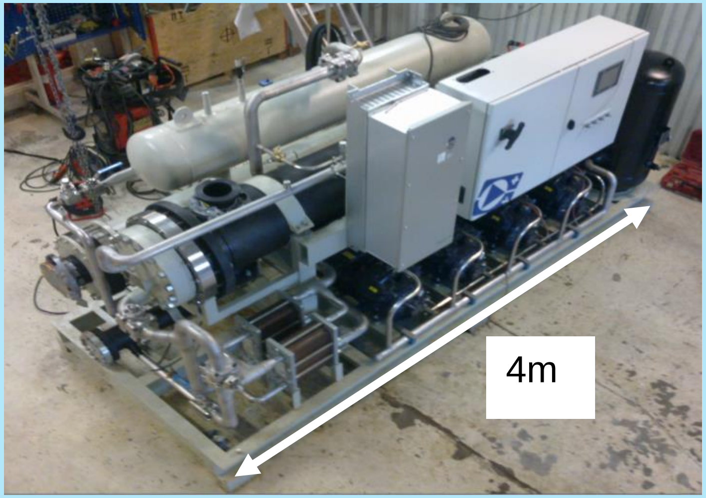
Fish industry

CO_2-RSW prototyp er installert på fiskebåt

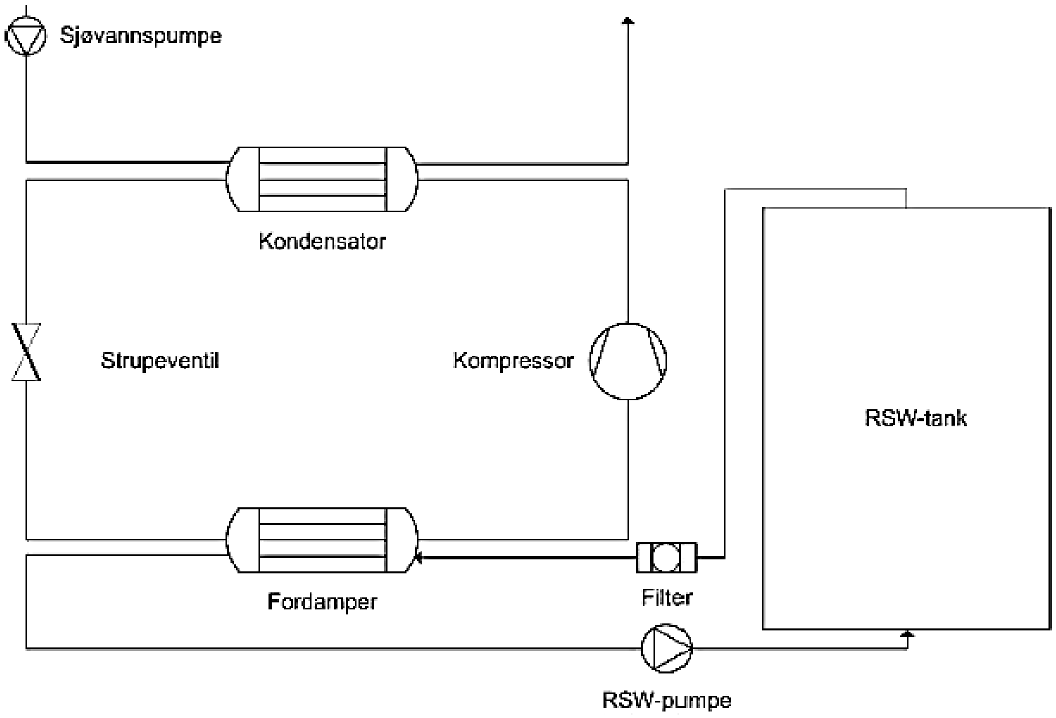
Miljøvennlig, ikke giftig kuldemedium, kompakt

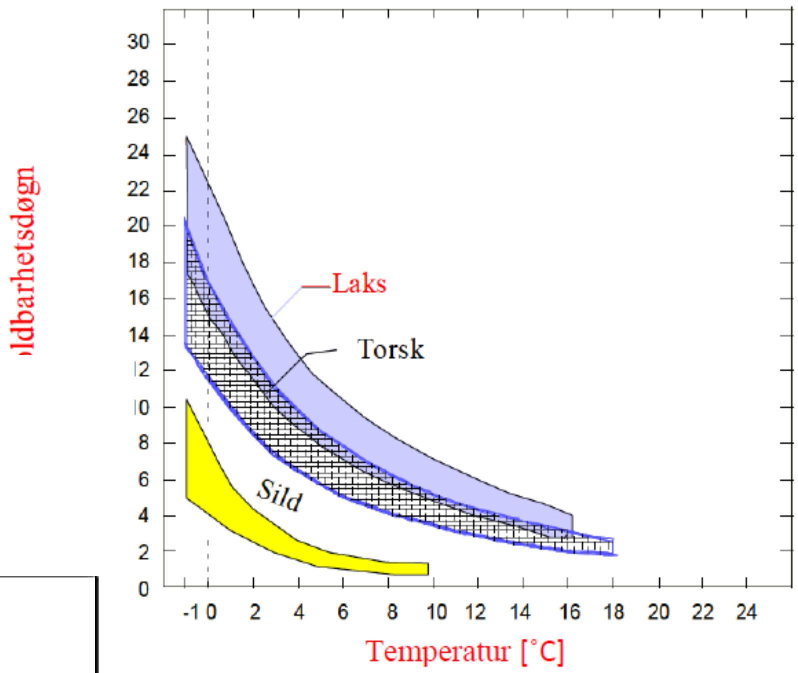
Kan gi **40 % redusert energibruk**

Egnet for retrofit



RSW





EU directive 92/48/EEC:
- < 3°C within 6 hours
- < 0°C within 16 hours

CO_2 RSW for fishing vessels: **impossible mission!**

- R22 phaseout 2015
- HFC not env alternative
- NH_3 not always sutiable

CO_2 RSW, operating experience 250kW plant onboard Båragutt MS

Design and analysis

End customer

SINTEF

NTNU

KULDE TEKNISK

Båragutt AS

Financing design

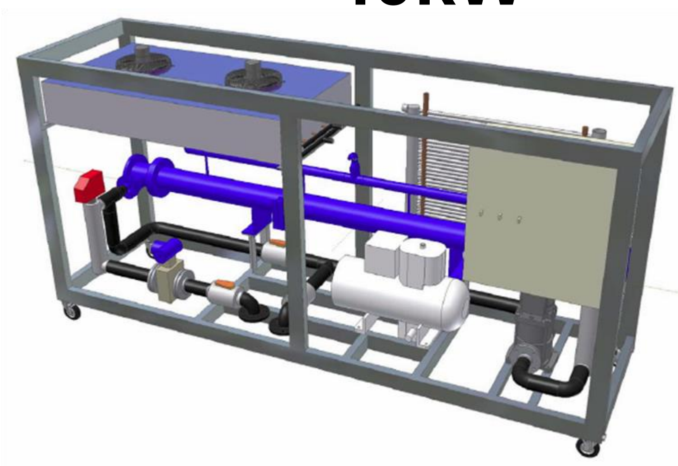
Engineering, building service

- Motivation: introduction of CO_2 technology in a new market
  - Non-flammable, non-toxic replacement for R22
  - Environmental technology
  - Compact and efficient tecnology with good part-load characteristics
  - Primary market: retrofit for existing vessels in the coast fisheries

From laboratory to full scale commerial plant

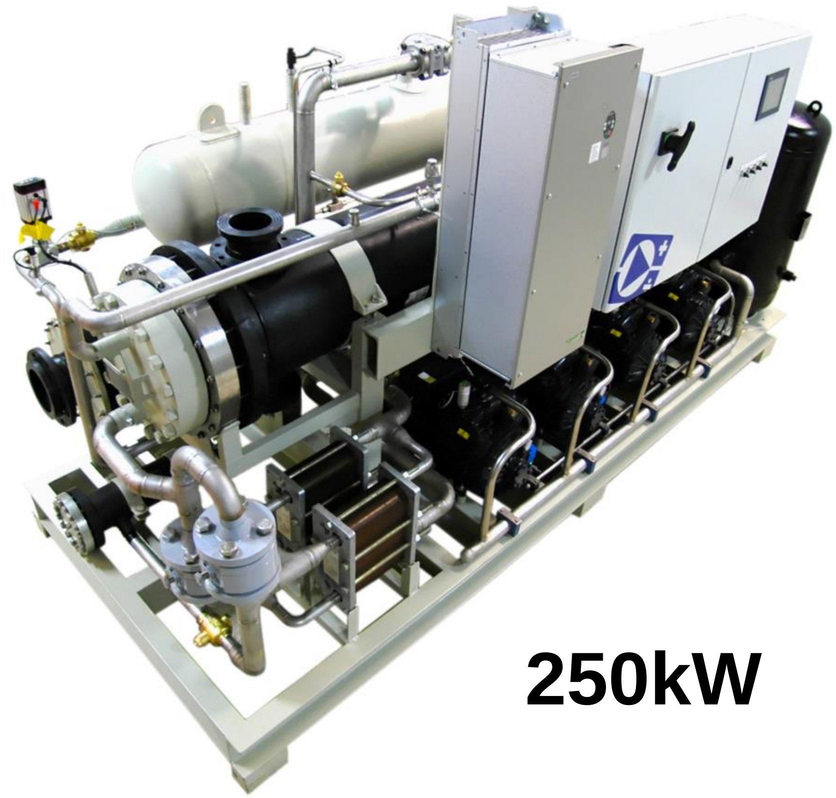
KULDE TEKNISK

40kW



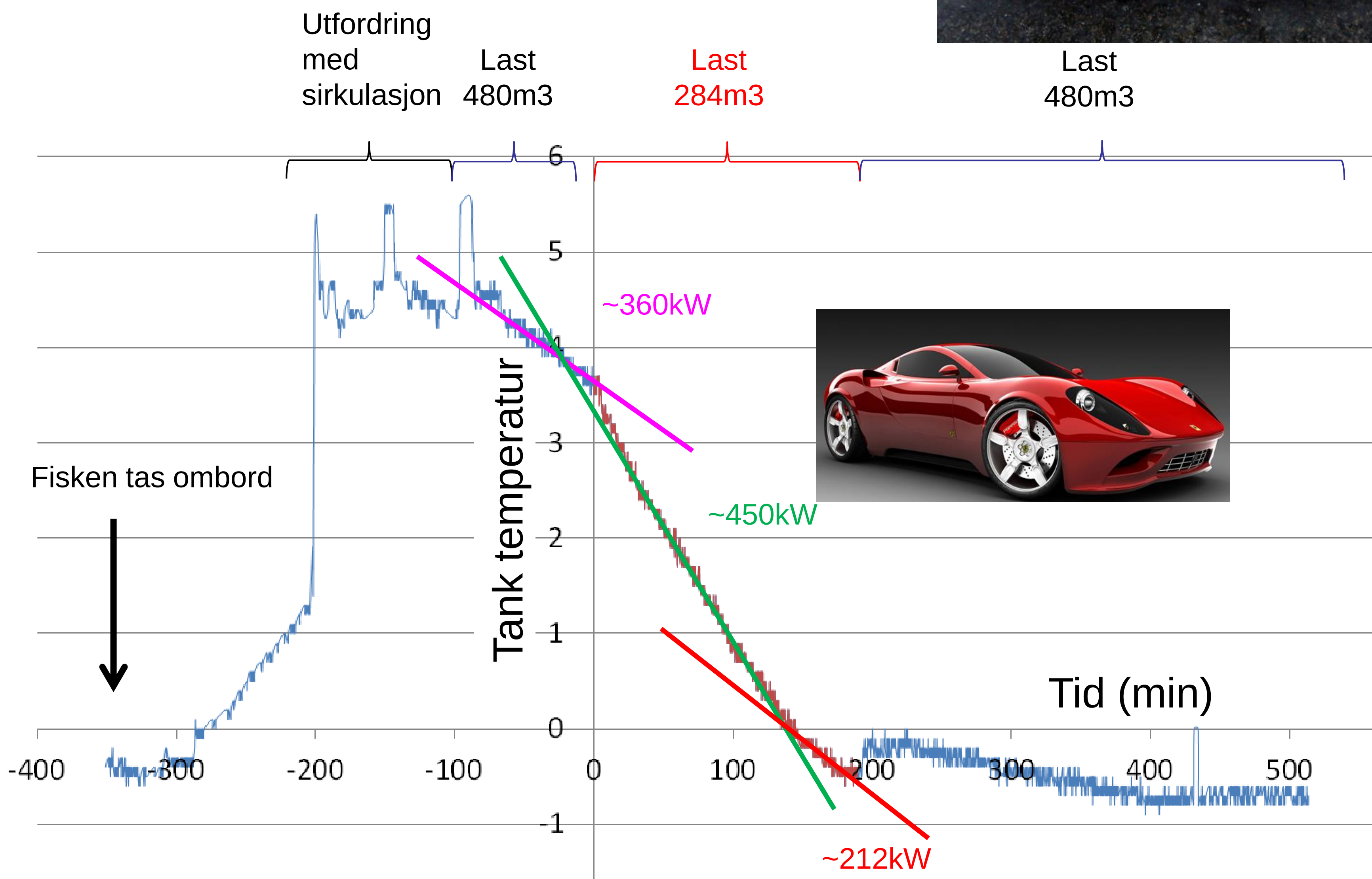
SINTEF

NTNU

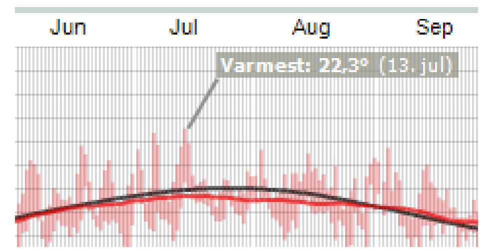


250kW

First throw: 300 tonnes capelin!



Summary first year of operation (cold!)



- Robust operation (tested in strong gale)
- Capacity control 100 -> 12.5% capacity, smooth start-up
- Approximately design capacity: 250kW 0 ->-1°C, -5°C evaporation temp
- High efficiency: COP = 4 - 6

Conclusions

- CREATIV has developed a lot of results contributing to more efficient refrigeration and heat pumping systems
- An important contribution has been made for the fundament for further development of energy efficient concepts
- Let us hope it will not be a "hvileskjær" in further development

We need to reduce

and GHG emissions

Thank you for your attention!

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