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Køle- og Varmepumpeforum 2021. Dansk Køledag 2021 & 7th International Symposium on Advances in Refrigeration and Heat Pump Technology

Samling af præsentationer

Elmegaard, Brian; Markussen, Wiebke Brix; Schøn Poulsen, Claus ; Bülow, Søren ; Sønder Nielsen, Jonas ; Fredslund, Kristian; Sørensen, Kenneth

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2021

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DTU Mechanical Engineering
Department of Mechanical Engineering

Køle- og Varmepumpeforum 2021

Dansk Køledag 2021 & 7th International Symposium on Advances in Refrigeration and Heat Pump Technology

Samling af præsentationer
Collection of presentations

Køle- og Varmepumpeforum 2021
Dansk Køledag 2021 &
7th International Symposium on Advances in Refrigeration and Heat Pump Technology

Samling af præsentationer
Collection of presentations
November 2021

By
Brian Elmegaard, Wiebke Brix Markussen, Claus Schøn Poulsen, Søren Bülow, Jonas Sønder Nielsen, Kristian Fredslund, Kenneth Sørensen

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www.mek.dtu.dk
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Forord

Køle- og Varmepumpeforum blev afholdt for anden gang den 4. oktober 2021. Det var en stor glæde for arrangørerne at vi langt om længe kunne afholde arrangementet, som grundet COVID-19 var blevet udsat af flere omgange i håbet om at vi kunne samle de danske interessenter indenfor fagområdet til et fysisk møde. Dette lykkedes i allerhøjeste grad. Næsten 300 deltagere var til stede ved dagen, og de benyttede lejligheden til at møde og udveksle nyt fra branchen med samarbejdspartnere, forretningsforbindelser, gode bekendte og nye ansigter med samme faglige interesse.

Arrangementet Køle- og Varmepumpeforum er en fælles afholdelse af Dansk Køledag og Symposiet Advances in Refrigeration and Heat Pump Technology, som begge har flere år på bagen som uafhængige arrangementer. Dansk Køledag arrangeres af foreningen af samme navn med fokus på at give deltagerne en faglig opdatering indenfor køleteknikken. Symposiet arrangeres af DTU og Teknologisk Institut med fokus på formidling af nye resultater fra forsknings- og udviklingsprojekter delvist finansieret af med offentlig støtte fx fra EUDP, Elforsk og Det Frie Forskningsråd.

Dagen blev afholdt med præsentationer i tre spor – to for Dansk Køledag og et for symposiet – efter en indledende hovedtale ved Marc Chasserot fra ATMOsphere (formerly shecco). Han åbnede dagen med at fokusere på naturlige kølemidlers potentiale og udfordringerne ved implementering af disse på verdensplan, i høj grad som kontrast til syntetiske kølemidler – eller med hans ord Clean vs. Dirty Cooling. I Dansk Køledags spor 1 blev der også fokuseret på kølemidler og deres miljøpåvirkning, samt regler relateret til dette. Spor 2 havde et mere teknisk fokus omkring store varmepumper, ammoniak som kølemiddel og nyt software. Symposiet blev startet af et indlæg fra Riley Barta, Technische Universität Dresden, som præsenterede seneste Trends inden for køling og varmepumper set fra et mere internationalt perspektiv. De øvrige indlæg dækkede fx soldrevet vaccinekøling, luft som varmekilde for store varmepumper og køling af elektronik-komponenter.

Arrangørerne vil hermed takke alle talere og deltagere for deres bidrag til at gøre dagen til en succes, som det har været en stor fornøjelse for os at få lov til at arrangere.

Danske Køledage
Søren Bülow, Dansk Køl & Varme
Jonas Sønder Nielsen, DKVF, Dansk Køle- og Varmepumpeforening
Kristian Fredslund, Cool Consult
Kenneth Sørensen, Sabroe Nordic

Teknologisk Institut
Claus Schøn Poulsen

DTU Mekanik
Wiebke Brix Markussen
Brian Elmegaard

Preface

Køle- og Varmepumpeforum was held for the second time on October 4, 2021. It was a great pleasure for the organizers that we were finally able to hold the event, which due to COVID-19 had been postponed several times in the hope that we could gather the Danish stakeholders in the field for a physical meeting. This succeeded to a very high degree. Almost 300 participants were present at the day, and they took the opportunity to meet and exchange news from the industry with partners, business associates, good acquaintances and new faces with the same professional interest. The event Cooling and Heat Pump Forum is a joint meeting between Dansk Køledag and Symposium on Advances in Refrigeration and Heat Pump Technology, both of which have several years behind them as independent events. Dansk Køledag is organized by the association of the same name with a focus on giving the participants a professional update within cooling technology. The symposium is arranged by DTU and the Danish Technological Institute with a focus on disseminating new results from research and development projects partly funded by public sources like EUDP, Elforsk and the Danish Independent Research Council.

The day was held with presentations in three tracks - two for Dansk Køledag and one for the symposium - after an introductory keynote speech by Marc Chasserot from ATMOsphere (formerly shecco). He opened the day by focusing on the potential of natural refrigerants and the challenges of implementing them worldwide, largely in contrast to synthetic refrigerants - or in his words Clean vs. Dirty Cooling. In Dansk Køledags spor 1, there was also a focus on refrigerants and their environmental impact, as well as regulation related to this. Track 2 had a more technical focus on large heat pumps, ammonia as a refrigerant and new software. The symposium was started by a talk by Riley Barta, Technische Universität Dresden, who presented the latest trends in cooling and heat pumps from a more international perspective. The other talks covered, for example, solar-powered vaccine cooling, air as a heat source for large heat pumps and cooling of electronic components.

The organizers thank all speakers and participants for their contribution to making the day a success, which it was a great pleasure for us to be allowed to organize.

Danske Køledage
Søren Bülow, Dansk Køl & Varme
Jonas Sønder Nielsen, DKVF, Dansk Køle- og Varmepumpeforening
Kristian Fredslund, Cool Consult
Kenneth Sørensen, Sabroe Nordic

Danish Technological Institute
Claus Schøn Poulsen

DTU Mechanical Engineering
Wiebke Brix Markussen
Brian Elmegaard

Indhold

1 Keynote Køle- og varmepumpeforum 2021

1.1 The Future of Cooling (& Heating): Dirty vs Clean, Marc Chasserot, ATMOsphere


ATMO sphere
Scaling the Clean Cooling Economy
www.atmosphere.cool


ATMO sphere
The Future of Cooling (& Heating): Dirty vs Clean
Marc Chasserot
Founder of ATMOsphere

ATMO sphere

shecco.com

ATMO sphere

ATMOsphere is a global, independent market accelerator with a mission to clean up cooling.

Cooling & Heating markets are experiencing significant disruption and innovation.

Investors, end users, manufacturers need support to navigate this complex landscape.

ATMO sphere

Scaling the Clean Cooling Economy

Connect
Engage in real time with hundreds of like-minded cooling experts worldwide

Report
Annual update to understand the latest market trends, technologies and players

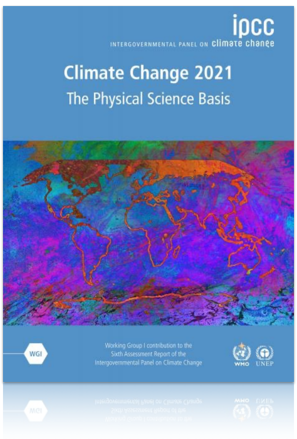
Marketplaces
Curated natural refrigerant products and services with news

Virtual Trade Show
THE annual 24-hour global trade show & summit with multi-platform livestreaming

Conferences
Defining the future of cooling via exclusive in-person networking & best-practice

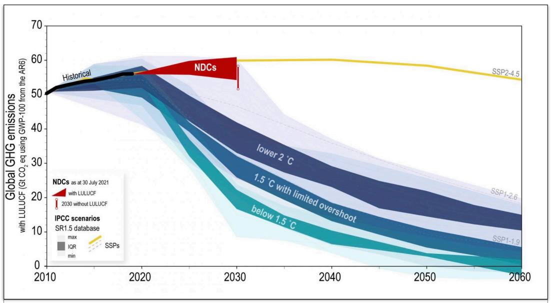
Associates
Find an expert to help your team design a product, process, and/or strategy

ATMO sphere



"Unless there are immediate, rapid and large-scale reductions in greenhouse gas emissions, limiting warming to close to 1.5°C (2.7°F) or even 2°C (3.6°F) will be beyond reach"

ATMO sphere



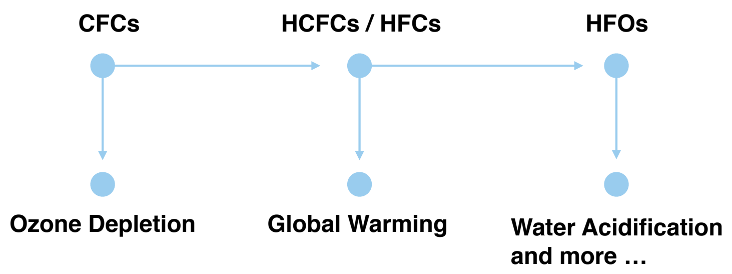
Carbon emissions are on track to rise by 16% by 2030, according to the UN, rather than fall by half, which is the cut needed to keep global heating under the internationally agreed limit of 1.5C. (source: UN NDC Synthesis Report, Sept 2021)

ATMO sphere

8 Years

Dirty Cooling vs. Clean Cooling

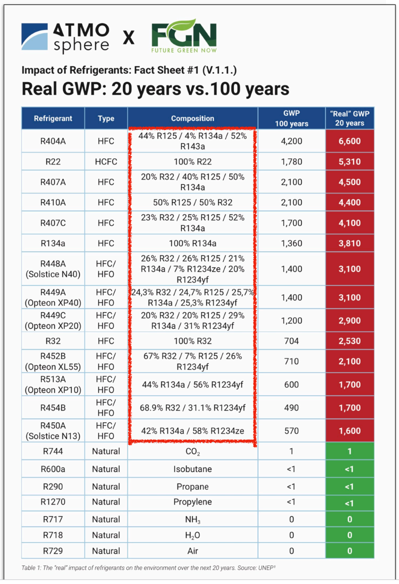
Dirty Cooling Paradigm



GWP-100 vs GWP-20

- Impact of Refrigerants Factsheet - massive response online
- Compares GWP of refrigerants over 20 years vs 100 years
- Atmospheric lifetime of most refrigerants closer to 20 years
- Don't have 100 years to address climate emergency
- IPCC 6 confirms GWP of all NatRefs as 1 or lower
- (Hydrocarbons also below 1 now)
- IPCC 6 confirms higher R32 GWP, even GWP-100 (now 771)

- Free download on: https://atmosphere.cool/knowledge/

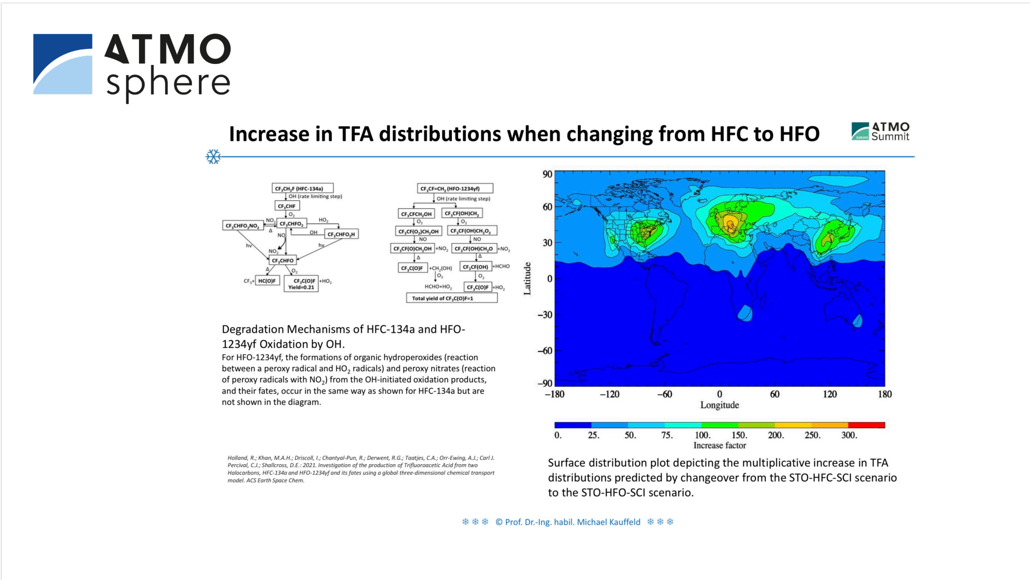


Impact of Refrigerants: Fact Sheet #1 (V.1.1.)

Real GWP: 20 years vs.100 years

Refrigerant	Type	Composition	GWP 100 years	"Real" GWP 20 years
R404A	HFC	44% R125 / 4% R134a / 52% R143a	4,200	6,600
R22	HCFC	100% R22	1,780	5,310
R407A	HFC	20% R32 / 40% R125 / 50% R134a	2,100	4,500
R410A	HFC	50% R125 / 50% R32	2,100	4,400
R407C	HFC	23% R32 / 25% R125 / 52% R134a	1,700	4,100
R134a	HFC	100% R134a	1,360	3,810
R448A (Solstice N40)	HFC/ HFO	26% R32 / 26% R125 / 21% R134a / 7% R1234ze / 20% R1234yf	1,400	3,100
R449A (Opteon XP40)	HFC/ HFO	24,3% R32 / 24,7% R125 / 25,7% R134a / 25,3% R1234yf	1,400	3,100
R449C (Opteon XP20)	HFC/ HFO	20% R32 / 20% R125 / 29% R134a / 31% R1234yf	1,200	2,900
R32	HFC	100% R32	704	2,530
R452B (Opteon XL55)	HFC/ HFO	67% R32 / 7% R125 / 26% R1234yf	710	2,100
R513A (Opteon XP10)	HFC/ HFO	44% R134a / 56% R1234yf	600	1,700
R454B	HFC/ HFO	68.9% R32 / 31.1% R1234yf	490	1,700
R450A (Solstice N13)	HFC/ HFO	42% R134a / 58% R1234ze	570	1,600
R744	Natural	CO_2	1	1
R600a	Natural	Isobutane	<1	<1
R290	Natural	Propane	<1	<1
R1270	Natural	Propylene	<1	<1
R717	Natural	NH_3	0	0
R718	Natural	H_2O	0	0
R729	Natural	Air	0	0

Table 1: The "real" impact of refrigerants on the environment over the next 20 years. Source: UNEP[1]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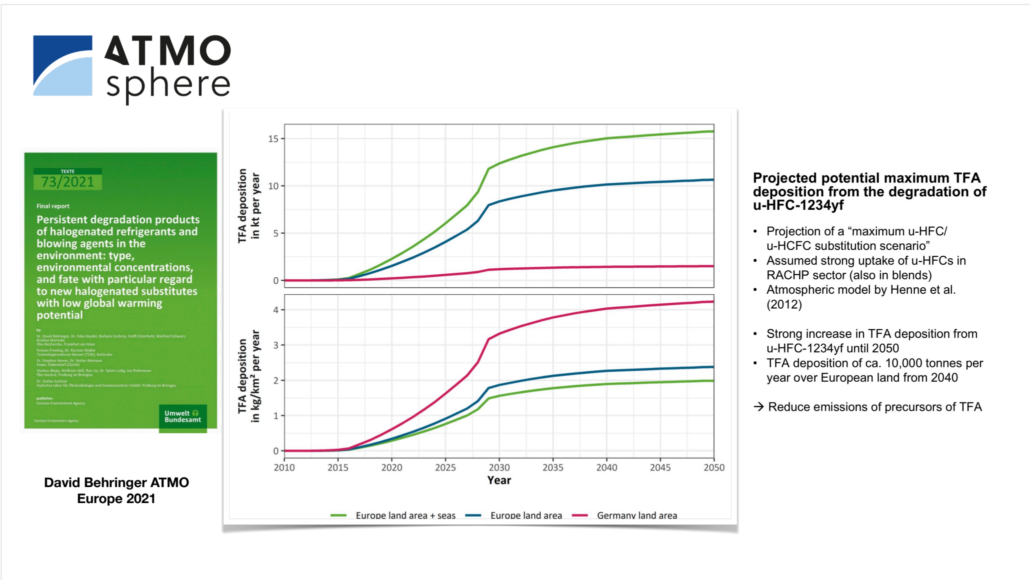
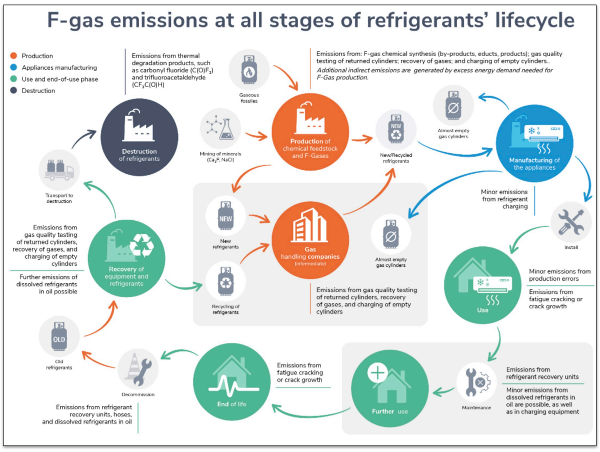
Increase in TFA distributions when changing from HFC to HFO
ATMO Summit
Degradation Mechanisms of HFC-134a and HFO-1234yf Oxidation by OH.
For HFO-1234yf, the formations of organic hydroperoxides (reaction between a peroxy radical and HO2 radicals) and peroxy nitrates (reaction of peroxy radicals with NO2) from the OH-initiated oxidation products, and their fates, occur in the same way as shown for HFC-134a but are not shown in the diagram.
Holland, R.; Khan, M.A.H.; Driscoll, I.; Chantyal-Pun, R.; Derwent, R.G.; Taatjes, C.A.; Orr-Ewing, A.J.; Carl J. Percival, C.J.; Shallcross, D.E.: 2021. Investigation of the production of Trifluoroacetic Acid from two Halocarbons, HFC-134a and HFO-1234yf and its fates using a global three-dimensional chemical transport model. ACS Earth Space Chem.
Latitude
Longitude
Increase factor
Surface distribution plot depicting the multiplicative increase in TFA distributions predicted by changeover from the STO-HFC-SCI scenario to the STO-HFO-SCI scenario.
© Prof. Dr.-Ing. habil. Michael Kauffeld


ATMO sphere
TEXTE 73/2021
Final report
Persistent degradation products of halogenated refrigerants and blowing agents in the environment: type, environmental concentrations, and fate with particular regard to new halogenated substitutes with low global warming potential
Umwelt Bundesamt
David Behringer ATMO Europe 2021
TFA deposition in kt per year
TFA deposition in kg/km² per year
Year
Europe land area + seas
Europe land area
Germany land area
Projected potential maximum TFA deposition from the degradation of u-HFC-1234yf
• Projection of a "maximum u-HFC/ u-HCFC substitution scenario"
• Assumed strong uptake of u-HFCs in RACHP sector (also in blends)
• Atmospheric model by Henne et al. (2012)
• Strong increase in TFA deposition from u-HFC-1234yf until 2050
• TFA deposition of ca. 10,000 tonnes per year over European land from 2040
→ Reduce emissions of precursors of TFA



ECOS: One Step Forward, Two Steps Back

REACH / PFAS 'Forever Chemicals'

Per- and polyfluoroalkyl substances (PFAS)

EC / List no: - **CAS no:** -

CLP Annex VI Index number	
Further substance information	PFAS in the scope of this restriction intention have the following structural formula: X-(-CF2-)n-X' with n equal to or larger than 1 and X, X' not being H (thus including X-CF3), meaning fluorinated substances that contain at least one aliphatic carbon atom that is both, saturated and fully fluorinated, i.e. any chemical with at least one perfluorinated methyl group (-CF3) or at least one perfluorinated methylene group (-CF2-), –), including branched fluoroalkyl groups and substances containing ether linkages, fluoropolymers and side chain fluorinated polymers.
Submitter(s)	Germany Denmark Netherlands Norway Sweden
Details on the scope of restriction	Restriction on manufacture, placing on the market and use of PFAS.
Reason for restriction	All PFAS are, or ultimately transform into, persistent substances, leading to irreversible environmental exposure and accumulation. Due to their water solubility and mobility, contamination of surface, ground-, and drinking water and soil has occurred in the EU as well as globally and will continue. It has been proven very difficult and extremely costly to remove PFAS when released to the environment. In addition, some PFAS have been documented as toxic and/or bioaccumulative substances, both with respect to human health as well as the environment. Without taking action, their concentrations will continue to increase, and their toxic and polluting effects will be difficult to reverse.
Remarks	Stakeholders are requested to provide relevant information to the Dossier Submitter. If justified based on robust risk and socio-economic information the Dossier Submitter may propose derogations from the proposed restriction. If a derogation is not proposed by the Dossier Submitter then it will be incumbent on the relevant stakeholders to do so during any consultation process with a full risk and socio-economic justification accompanying it.
Status	Intention
Date of intention	15/07/2021
Expected date of submission	15/07/2022
Withdrawal date	
Reason for withdrawal	
Start of Call for Evidence consultation	19/07/2021
Deadline for comments on the Call for Evidence	17/10/2021

ATMO sphere

Dirty Cooling vs. Clean Cooling

ATMO sphere

Clean Cooling Opportunity


Centre for Sustainable Cooling ATMO sphere

Defining 'Clean Cooling'

Comprehensive Clean Cooling – which will include standards by which to measure the impact of cooling systems – is a prerequisite for a sustainable and resilient future.

Introduction

"Cooling" refers to any human activity, design or technology that dissipates heat and reduces temperatures, typically including refrigeration and air conditioning. Cooling contributes, in both the built and transport environments, to achieving: (i) safe/adequate thermal comfort for people, or (ii) preservation of products (food, medicines, vaccines, etc.), or (iii) effective and efficient processes (for example, data centres, industrial or agricultural production, and mining).

Recognising both the growth in demand for cooling and the paradigm shifts that are affecting both our communities and global markets, we developed the term "**Clean Cooling**" to take cooling to a much higher level, encompassing a portfolio of elements outlined below. "The Clean Cooling Landscape Assessment," was published in 2018 and released at the 24th Conference of the Parties to the United Nations Framework Convention on Climate Change (COP24), with support from the Kigali Cooling Efficiency Programme (K-CEP) and endorsements from Mission Innovation and the U.K.'s Department of Business, Energy and Industrial Strategy (www.clean-cooling.ac.uk).

To build on the work to date, and to help accelerate the transition from traditional cooling to **Clean Cooling**, the Centre for Sustainable Cooling and shecco are, over the course of 2020, leading a new collaborative project to develop a set of measurable standards for **Clean Cooling** against which cooling innovation and projects can be assessed. These standards will help all stakeholders to properly understand and quantify the true sustainability (financial, social and environmental) of cooling technology, including CO_2e emissions reduction. Depending on market interest, this could become the basis for a first-of-its-kind formal **Clean Cooling** Audit-and-Certification Program.

We accept **Clean Cooling** is setting a very high bar when compared with the many incremental improvements being rolled-out – and we absolutely recognise the value of every efficiency improvement, every use of lower GWP refrigerants. But given the size of both the societal and climate challenges we face, we need to go further, faster. We have to deliver the ambition of **Clean Cooling**. To achieve this, we have to properly define and quantify what that means and be able to assess the extent to which new cooling systems meet the challenge.

As we create the framework for the definition and measurement of **Clean Cooling**, we welcome comments from all stakeholders.

Clean Cooling is the benchmark at the intersection of the Paris Climate Agreement, the **Kigali Amendment** of the Montreal Protocol and the sustainable development goals.

Clean Cooling aims to be the 'gold standard for sustainable cooling'

Good news is that the fastest way to achieve Clean Cooling is through natural refrigerants

info: ATMOsphere.cool

Clean Cooling Opportunity

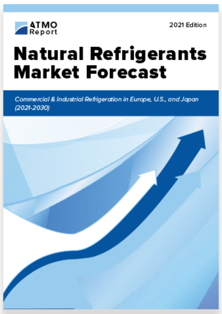
- Starting with understanding the first principles of "what we are trying to do" to meet the cooling needs for all;
- Prioritising how to mitigate cooling demand and meet it through behaviour change and design;
- Recognising the portfolio of free, natural and energy-waste resources to help meet demand;
- Defining the right mix of energy sources, natural refrigerants[i], thermal energy storage, cooling technologies, business models, manufacturing, maintenance regimes, end-of-life management and policy interventions – and then to optimally, *and safely,* integrate all available energy resources through complete system approaches;
- In short, thinking thermally, which means, among other things, defining a new set of incentives and behaviour changes that impact individual and organisational decisions - how we mitigate cooling demand; de-electrify cooling where possible; store energy for use on-demand; balance heating and cooling; and transition fully from fluorinated to natural refrigerants;
- Also ensuring that we have an adequate skilled workforce to design, install and maintain **Clean Cooling** systems;
- Finally, in delivering the above, driving inclusive and sustainable industrialisation in a holistic approach to create resilient and future-proof communities.

	CO2 / R744	NH3 / R717	HC	H2O / R718	Air / R729
Domestic applications	☺		☺		
Commercial refrigeration	☺	☺	☺		
Industrial refrigeration and heat pump systems,	☺	☺	☺	☺	
Water and space heating heat pumps	☺	☺	☺		
Chillers	☺	☺	☺	☺	
Vehicle air conditioning	☺		☺		☺

Armin Hafner, ATMO Europe 2021

ATMO Summit EUROPE

Annual Report



Natural Refrigerants Market Forecast (2021 Edition)

ATMOsphere's annual update on the latest market trends (including policy), market size, and expected growth for commercial and industrial refrigeration in Europe, the U.S. and Japan (2021-2030).

www.atmosphere.cool/product/natural-refrigerants-market-forecast-2021-edition

28-29/09/2021 - Online

#GoNatRefs

ATMO sphere

Natural Refrigerant Market is Booming

"In my 20 years of working in the natural refrigerants marketplace, I can unequivocally say that natural refrigerants have never had it so good."

– Marc Chasserot, ATMOsphere Founder & Publisher

ATMO sphere

Trends: Drivers vs. Barriers

ATMO sphere

MARKET SIZE
A Sneak Peek into the Report

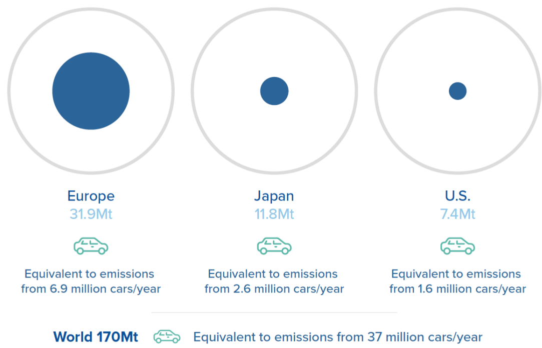
Future Projections – 2025 and Beyond

Each region includes current market and 2025 projections for:

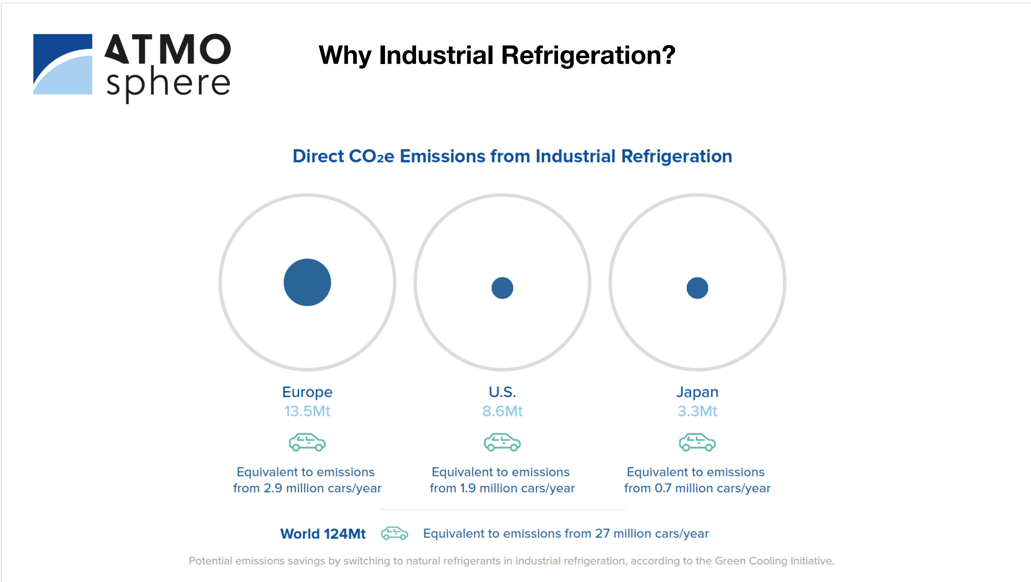
1. *Commercial Refrigeration*: Transcritical CO_2
2. *Commercial Refrigeration*: Hydrocarbons
3. *Industrial Refrigeration*: Transcritical CO_2
4. *Industrial Refrigeration*: Low-charge Ammonia

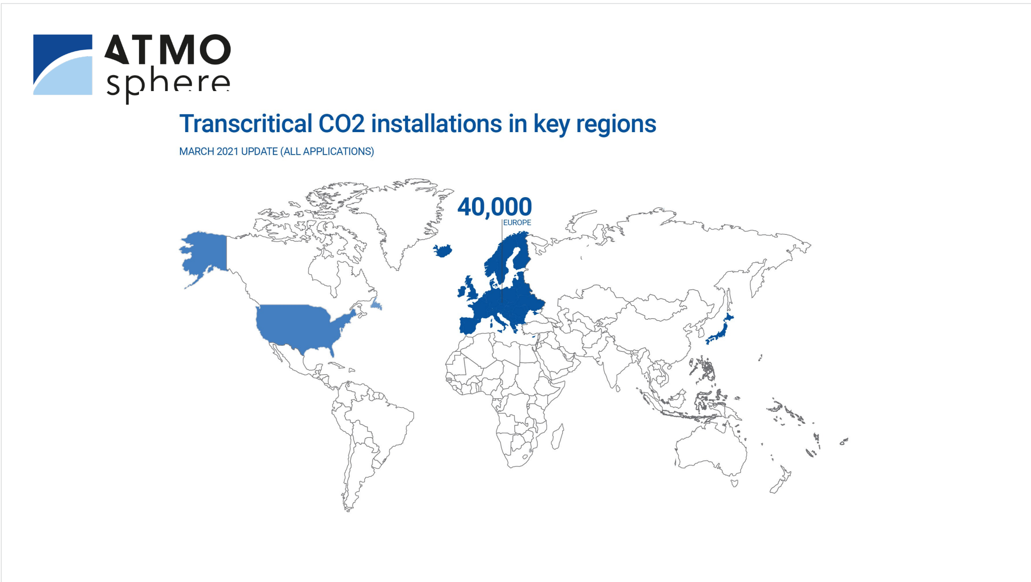
Why Commercial Refrigeration?

Direct CO₂e Emissions from Commercial Refrigeration

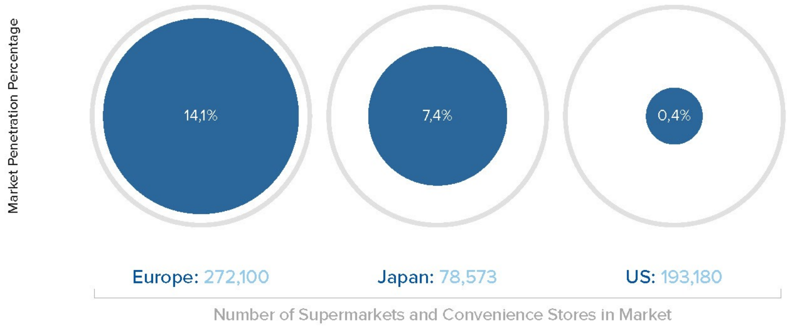


Potential emissions savings by switching to natural refrigerants in commercial refrigeration, according to the Green Cooling Initiative.


ATMO sphere
Why Industrial Refrigeration?
Direct CO2e Emissions from Industrial Refrigeration
Europe
13.5Mt
Equivalent to emissions from 2.9 million cars/year
U.S.
8.6Mt
Equivalent to emissions from 1.9 million cars/year
Japan
3.3Mt
Equivalent to emissions from 0.7 million cars/year
World 124Mt
Equivalent to emissions from 27 million cars/year
Potential emissions savings by switching to natural refrigerants in industrial refrigeration, according to the Green Cooling Initiative.


ATMO sphere
Transcritical CO2 installations in key regions
MARCH 2021 UPDATE (ALL APPLICATIONS)
40,000
EUROPE

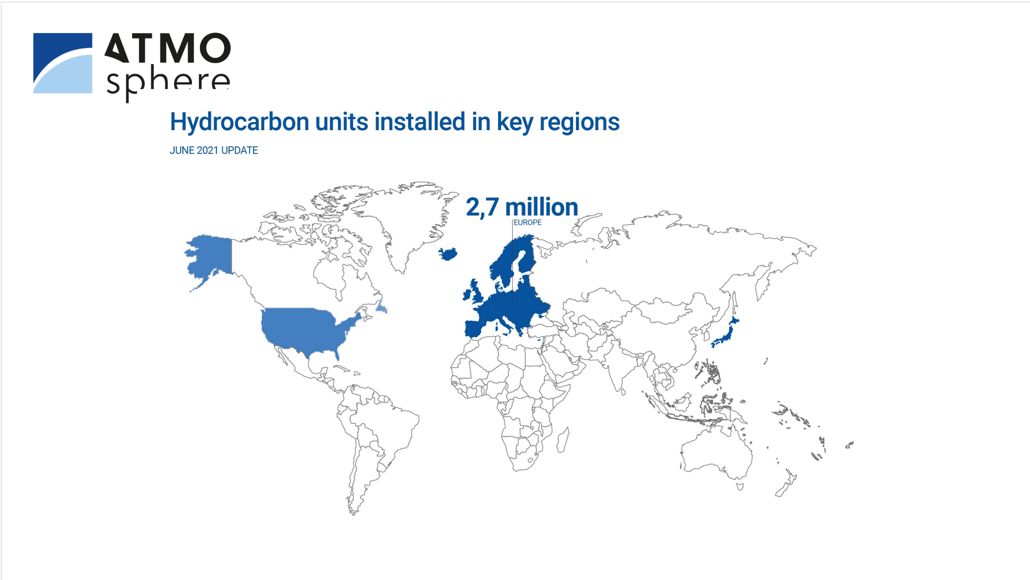
Transcritical CO_2 Commercial Refrigeration Market Penetration
(2021)

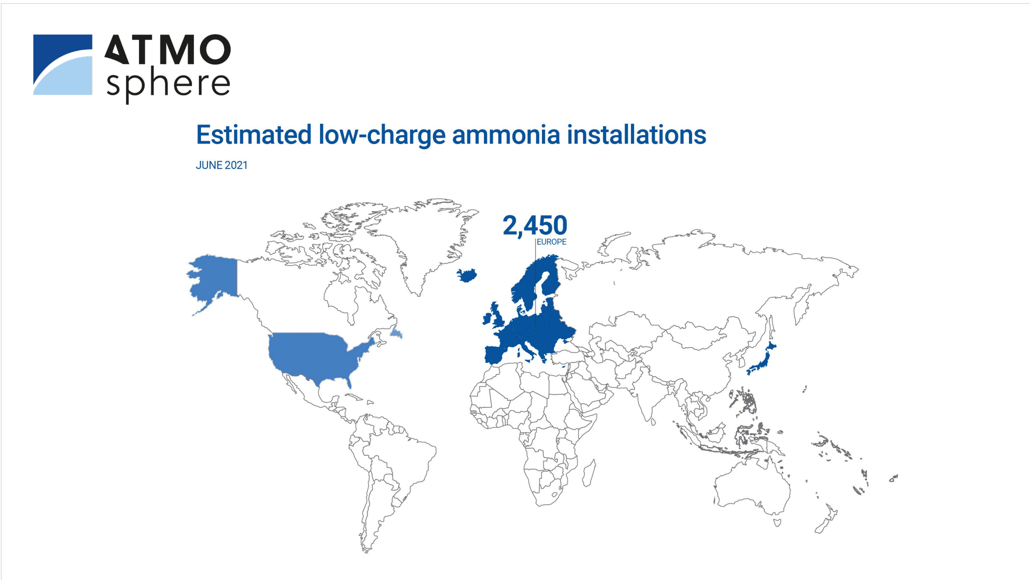


Poll Question – Vote Now

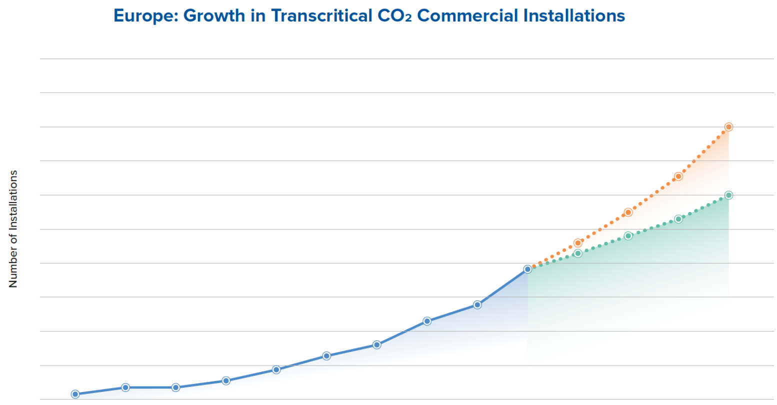
The transcritical CO_2 penetration rate in Commercial Refrigeration applications in Europe is currently 14,1%. What do you expect this rate to be by 2025?

> 15-20%
> 20-40%
> 40-60%
> Above 60%


ATMO
sphere
Hydrocarbon units installed in key regions
JUNE 2021 UPDATE
2,7 million
EUROPE


ATMO
sphere
Estimated low-charge ammonia installations
JUNE 2021
2,450
EUROPE

Future Projections – 2025 and Beyond



I choose Clean …
and you ?


ATMO
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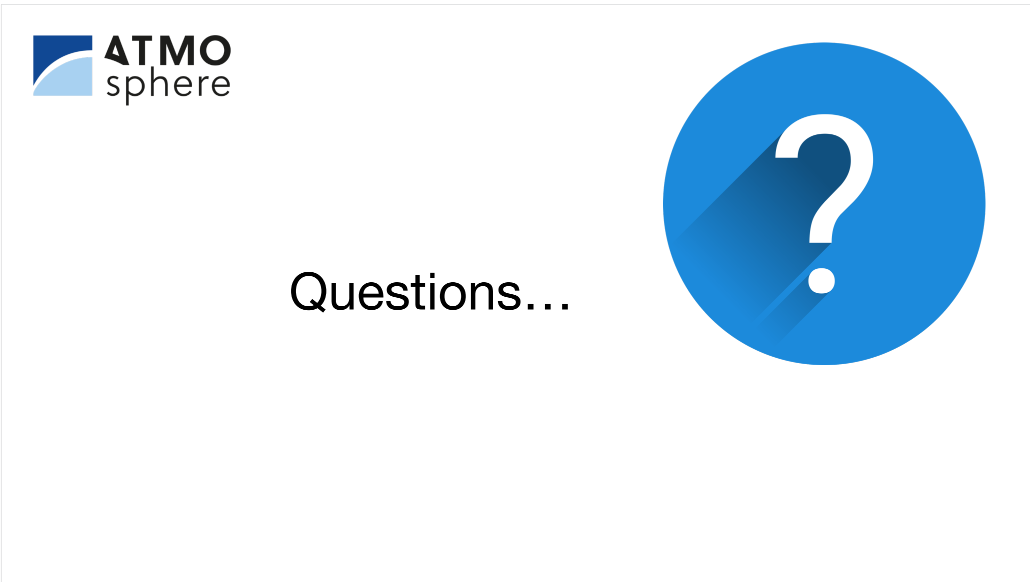
Thank you
for listening.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Questions…


ATMO sphere
Scaling the Clean Cooling Economy
www.atmosphere.cool

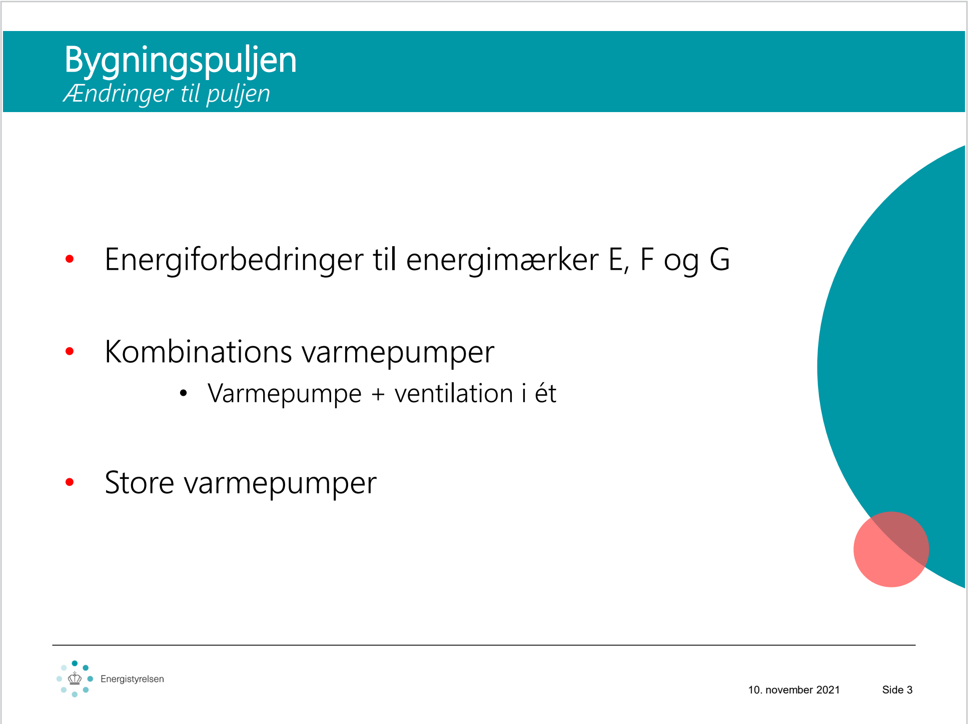
2 Dansk Køledag 2021

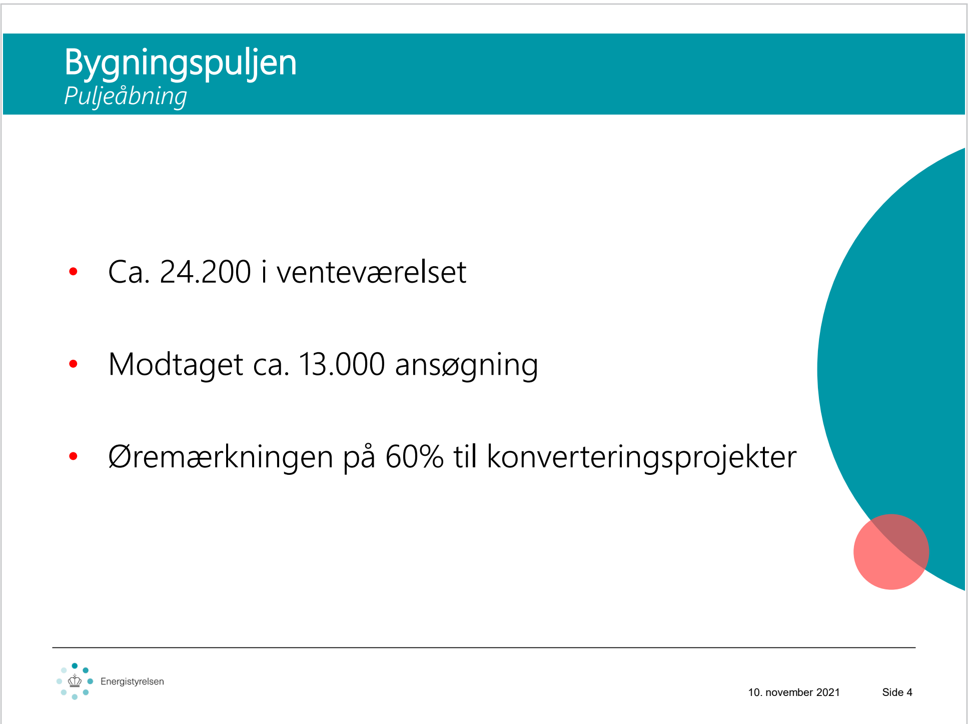
Bygningspuljen
Introduktion

- Tilskud til varmepumper
- Tilskud til klimaskærm og drift
- 60% øremærkning til varmepumpeprojekter
- Krav til varmepumperne

- Puljestørrelse 675 mio. i 2021
- Puljestørrelse 430 mio. i 2022
- Opdelt i flere ansøgningsrunder hvert år

Energistyrelsen 10. november 2021 Side 2


Bygningspuljen
Ændringer til puljen
• Energiforbedringer til energimærker E, F og G
• Kombinations varmepumper
• Varmepumpe + ventilation i ét
• Store varmepumper
Energistyrelsen
10. november 2021
Side 3


Bygningspuljen
Puljeåbning
• Ca. 24.200 i venteværelset
• Modtaget ca. 13.000 ansøgning
• Øremærkningen på 60% til konverteringsprojekter
Energistyrelsen
10. november 2021
Side 4

Kommune & regioner puljen

Endnu ikke åbnet første gang

- Energiforbedringer og digitale løsninger
- Krav om konvertering
- Krav til varmepumpen

- 150 mio. kr. i puljen i 2021
- 150 mio. kr. i puljen i 2022

Energistyrelsen 10. november 2021 Side 5

Skrotningsordningen

Varmepumper på abonnement

- Prækvalificerede leverandører
- Leverandøren ejer varmepumpen
- Forbruger betaler for den leverede varme

- 50 mio. i puljen i 2021
- 50 mio. i puljen i 2022

Energistyrelsen 10. november 2021 Side 6

VE-godkendelsesordningen

- Virksomheder kan godkendes til montering af biomassekedler og –ovne, solcelleanlæg, solvarmeanlæg, og varmepumper og systemer til overfladenær udnyttelse af geotermisk energi
- Ordningen har baggrund i VE-direktivet
- Bekendtgørelse nr. 1047 af 26/08 2013, bekendtgørelse nr. 1229 af 28/10 2013 og bekendtgørelse nr. 1317 af 18/06 2021
- VE-godkendelsesordningen består af ca. 1050 VE-godkendte virksomheder

Energistyrelsen 10. november 2021 Side 8

Klimaaftalen

Understøttende tiltag fra "Opfølgende aftale ifm. Klimaftale for energi og industri mv."

- Undersøgelse af, om VE-godkendelsesordningen bør gøres obligatorisk for varmepumper udvides til også at omfatte en undersøgelse af, hvordan ordningen kan forbedres og tilpasses det fremtidige marked.
- Serviceintervallet for små varmepumper i private husholdninger ændres fra et til to år for at reducere omkostningerne ved at eje en varmepumpe og frigøre installatørressourcer.
- Mulig tilføjelse af et energimæssigt element til serviceeftersynet af små varmepumper.

Energistyrelsen

10. november 2021 Side 9

Analyse af VE-godkendelsesordningen

- Energistyrelsen er i gang med at få udarbejdet en analyse af VE-godkendelsesordning af Viegand Maagøe
- *Obligatorisk ordning – 2 scenarier*
  - Basismodel med fortsættelse af nuværende model
  - Model med uddannelseskrav der er målrettet udførende medarbejdere
- *Kompetencer og kvalifikationer blandt udførende medarbejdere*
- *Potentiel installatørmangel*
- *Kurser og kompetencekrav*
- *VE-godkendte virksomheders kvalitetsledelsessystem*

Energistyrelsen

10. november 2021 Side 10

Serviceinterval og serviceeftersyn

- Serviceintervallet for små varmepumper i private husholdninger ændres fra et til to år
  - Energistyrelsen er i dialog med Arbejdstilsynet, som står for serviceeftersynet
- Mulig tilføjelse af et energimæssigt element til serviceeftersynet af små varmepumper.
  - Energistyrelsen undersøger, hvorvidt et energimæssigt eftersyn giver besparelser og hvad et eftersyn vil skulle indeholde

Energistyrelsen

10. november 2021 Side 11

Den gode installation af varmepumper (2021)

- Den gode installation af varmepumper (2017)

"Af de 164 undersøgte væske/vand-varmepumpeanlæg var det kun omkring 15 %, der levede op til en forventet god SPF."

- Analysen udarbejdes af Teknologisk Institut for Energistyrelsen
- Formålet er at skabe overblik over kvaliteten af varmepumpeinstallationer

Energistyrelsen

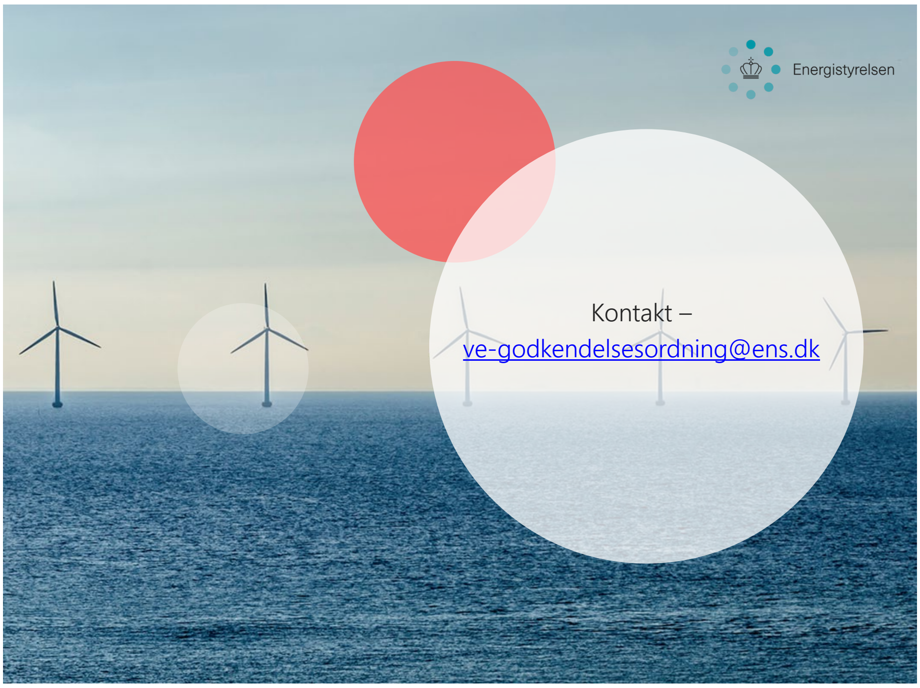
10. november 2021 Side 12

Analyse af energibesparelser i luft til luft-varmepumper

- Teknologisk Institut er i gang med at analysere energibesparelsespotentialet ved en mere energirigtig installation af luft til luft-varmepumper
- Dette skal analyseres i forbindelse med en mulig obligatorisk VE-godkendelsesordning

Energistyrelsen

10. november 2021 Side 13



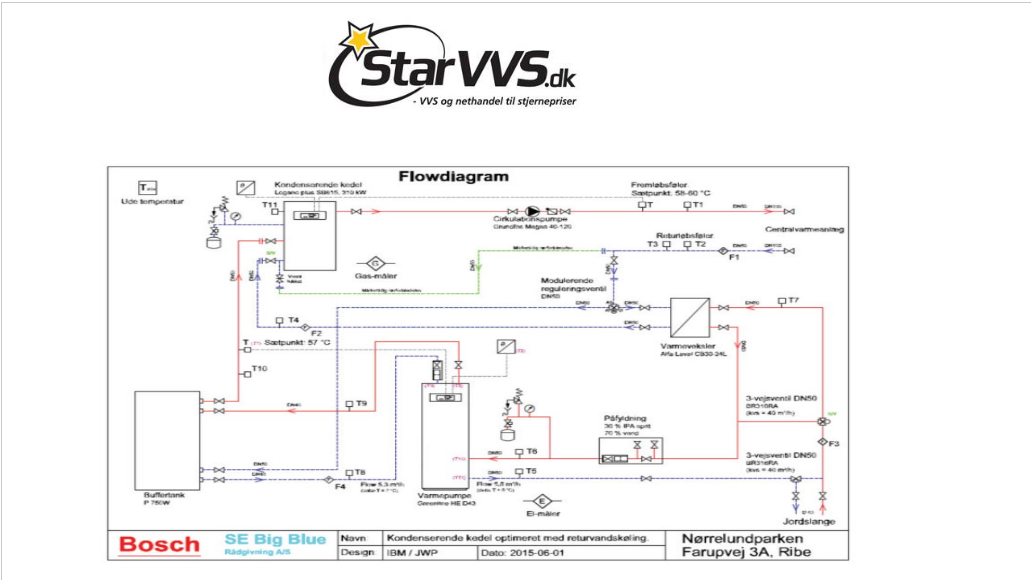
StarVVS.dk
- VVS og nethandel til stjernepriser

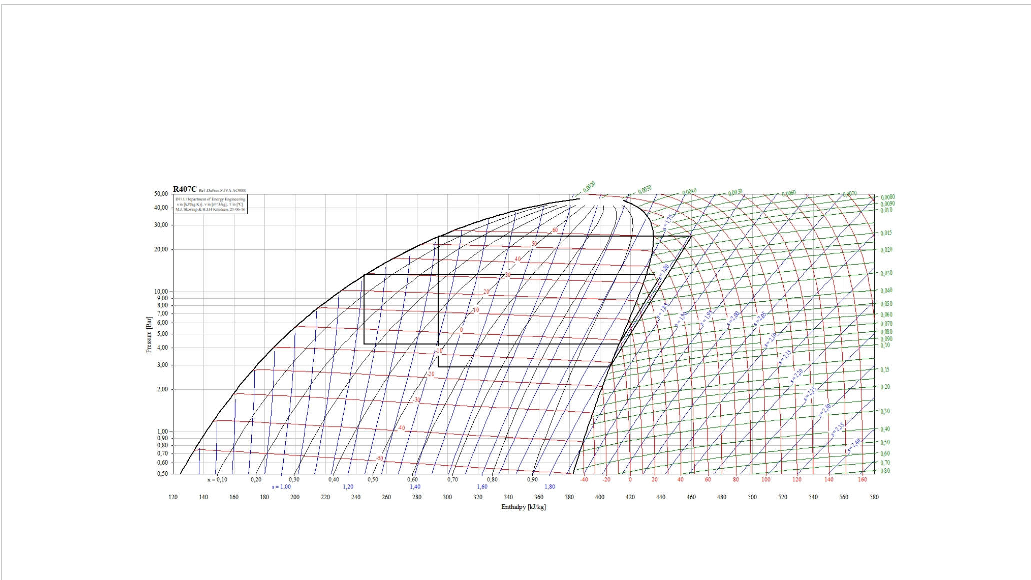
.

- **Peter Wagner Holst**
- Uddannet Vvs-tekniker
- Autoriseret Vvs-installatør
- A certifikat Køl op til 50 kg
- VE installatør
- Iso certificeret 9001
- Diplomleder

1

StarVVS.dk
- VVS og nethandel til stjernepriser


StarVVS.dk
- VVS og nethandel til stjernepriser
Flowdiagram
Kondenserende kedel
Fremløbsføler
Sætpunkt: 58-60 °C
Cirkulationspumpe
Centralvarmeanlæg
Returløbsføler
Gas-måler
Modulerende reguleringsventil
Sætpunkt: 57 °C
Varmeveksler
Buffertank
Varmepumpe
Påfyldning
3-vejsventil DN50
El-måler
Jordslange
Bosch
SE Big Blue
Rådgivning A/S
Navn
Kondenserende kedel optimeret med returvandskøling.
Design
IBM / JWP
Dato: 2015-06-01
Nørrelundparken
Farupvej 3A, Ribe


R407C
Pressure [Bar]
Enthalpy [kJ/kg]

Elforsk projekt

Konklusion og forslag til det videre forløb

- Ud fra analyserne kan det konkluderes, at der er tale om et interessant anlægsprincip, der fungerer. Anlægget benytter både gas og el og bygger derfor bro imellem de to energiformer.
- Analysen viser, at varmepumpen i følgeperioden opnår en COP på 3,15, og kedlen opnår en virkningsgrad på ca. 86 %. Denne kedelvirkningsgrad er dog ikke retvisende, da varmetab fra buffertank og rør på varmecentralen bliver pålagt gaskedlen, da der ikke sker direkte måling af kedelydelsen. Gaskedlen vil derfor have en højere virkningsgrad. Denne er ved nærmere analyse estimeret til at være ca. 106 %.
- Totalvirkningsgraden for anlægget i rapporteringsperioden er ca. 126 %, hvis elfaktor = 1 benyttes, og ca. 100 %, hvis elfaktor = 2,5 benyttes. Alle virkningsgrader er beregnet ud fra nedre brændværdi.
- Analysen har vist, at varmepumpen drives med forholdsvis høj fremløbstemperatur. Dette kan have negativ indvirkning på COP'en. Det bør derfor undersøges, om det er muligt at ændre anlægsdriften, så COP'en forbedres.
- Der er set meget lave returtemperaturer til kedlen - i perioder helt ned til omkring 10-15 °C. Dette medvirker til, at der opnås stor kondensation på kedlen.
- Den lave returtemperatur til kedlen kan dog have indvirkning på fremløbstemperaturen for varmepumpen, og det bør derfor undersøges, om kondenseringen evt. skal mindskes for at opnå bedre COP for varmepumpen.
- I kraft af overstående vil det være relevant at gennemføre en driftsmæssig optimering af anlægget (optimal prioritering af varmepumperne, fremløbstemperatur og fordeling af flow) og herefter følge udviklingen i virkningsgraden.
- Desuden bør der undersøges, hvilke muligheder der er for udbygning med gasvarmepumpe, enten luft eller vand, eller en evt. luft-til-vand-elvarmepumpe. Især udbygning med gasvarmepumpe er interessant; der er på varmepumpen store perioder med kontinuert drift, hvilket er særdeles velegnet til en gasvarmepumpe.

- DGC Bjørn K. Eliasen

Energi-,
Forsynings- og
Klimaministeriet

- Smart-hybridvarmevirksomhed til bygningsopvarmning
- DGC, DGD, Seas NVE, SE og Esbjerg kommune som anlægs vært
- StarVVS A/S står for udførelsen og CTS O/J Teknik

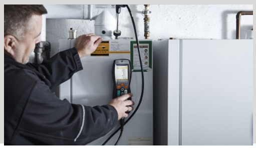
DEN HYBRIDE SKOLE Vi har netop færdiggjort installationen af fem METROAIR I20-varmepumper i en kaskadeløsning på Gredstedbro Skole i Jylland, hvor den samlede installation vil komme op på 16 varmepumper, når vi er færdige.

StarVVS.dk
- VVS og nethandel til stjernepriser

Konsolideret statsligt gasdistributionsselskab

- Energinet køber og overtager
  - DONG Gas Distribution den 1. oktober 2016
  - Nature Energy Distribution den 1. maj 2018
  - HMN Gasnet den 1. april 2019
  - Aalborg Bygas formentlig i løbet af sommeren 2019

- Realisering af synergier på ca. 100 mio. kr. om året.
- Del af Statens udflytningspakke 2
  - Hovedsæde i Viborg
  - Regionale driftscentre i Stenlille og Sydjylland
- Selskabet skal skilles ud af Energinet. Fortsat statsligt ejerskab placeret i Finansministeriet
- Gælden fra gasnettets etablering er betalt i 2025
- Fælles tariffer efter 2025
- Betalt infrastruktur til 55 mia. kr. står til rådighed for Danmark



7

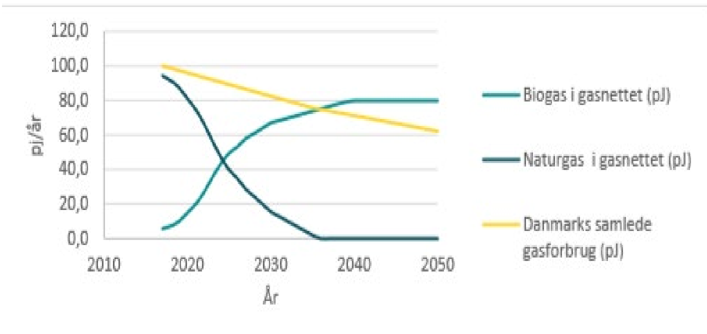
DGD DANSK GAS DISTRIBUTION

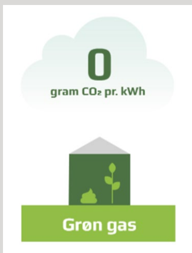
Opgaver

- Driver og vedligeholder gasnettet i Danmark
- Tilslutter nye kunder
- Tilslutter biogasproducenter
- 400.000 gaskunder
- 2 mia. m3 gas i årlig afsætning
- 55 mia. kr. har det samlede gassystem kostet
- På vej mod 20 pct. biogasandel i løbet af 2020

8

DGD DANSK GAS DISTRIBUTION


120,0
100,0
80,0
60,0
40,0
20,0
0,0
pj/år
2010
2020
2030
2040
2050
År
Biogas i gasnettet (pJ)
Naturgas i gasnettet (pJ)
Danmarks samlede gasforbrug (pJ)


0
gram CO₂ pr. kWh
Grøn gas

10

Økonomi

- Optimal kørsel med varmepumpe er -4 grader til max 40 grader
- En cop på op til 5
- Giver en pris på 30 øre/kW for alle evt. 90 % tid

- Mindre end -4 grader 0g større en 40 grader
- Bruges gas til en pris af 85 øre/kW
- El pris = 1,5 kr.
- Cop på 2 billigere at køre på gas

StarVVS.dk

- VVS og nethandel til stjernepriser

StarVVS

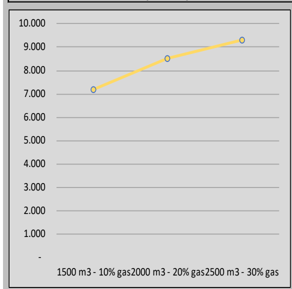
StarVVS A/S beregning på Daikin Altherma Hybrid

Gas pris pr. KW	kr.	0,85	Gas pris i dag	kr.	21.250	
El pris pr. KW	kr.	1,50	Pris v. hybrid	kr.	8.821	
CoP		5,04	**Besparelse**	**kr.**	**12.429**	**pr. år**

Gas forbrug i hustand m3	2.500
Gas forbrug i hustand KW	25.000

	Gas	El
% forbrug	10%	90%
Forbrug split i KW	2.500	22.500
Total forbrug split	kr. 2.125	kr. 6.696

Besparelse potentiale ved faste forudsætninger



Type	Besparelse
1500 m3 - 10% gas	7.189
2000 m3 - 20% gas	8.521
2500 m3 - 30% gas	9.319

Copyright

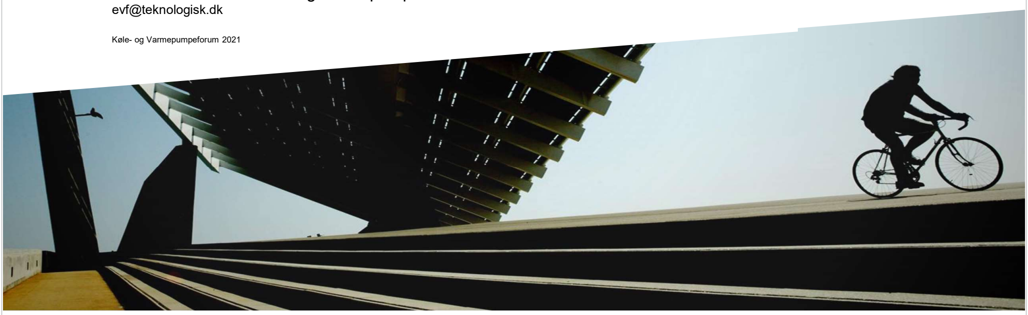
- Energimærkning Opmålt ud fra en given temperatur 2,5 i forhold til El
- COP /SCOP Faste Grader 7 -35 grader
- Hvis jeg tager fabrikanternes ord, så må der være anden opvarmning uden for disse områder
- Fuldstændig forvirrende for den enkelte forbruger

- Ældre hus 50 grader i Fremløb
- Udetemperatur minus 12, Hvad er min COP hvor stor skal min varmepumpe være ????
- Derfor Hybrid
- Alt andet er volapyk ☺

Ecodesign – en barriere eller en mulighed?

Esben Vendelbo Foged
Sektionsleder ved Køle- og Varmepumpeteknik
evf@teknologisk.dk

Køle- og Varmepumpeforum 2021

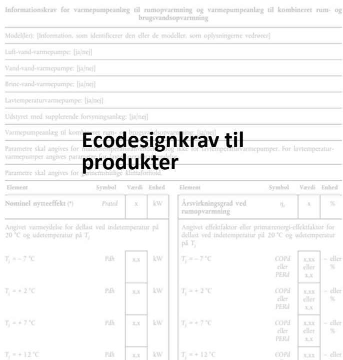


Engelsk vs. Dansk

Ecodesign aka ”Miljøvenligt Design”

Hvad er Energimærkning og Ecodesign?

Energimærkning af produkter

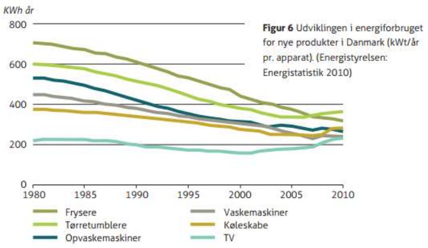


Ecodesignkrav til produkter

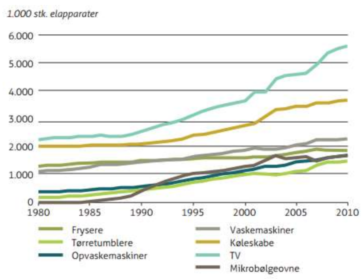
TEKNOLOGISK INSTITUT

Hvorfor energibesparelser? Danske øjne

Årligt energiforbrug pr. apparat



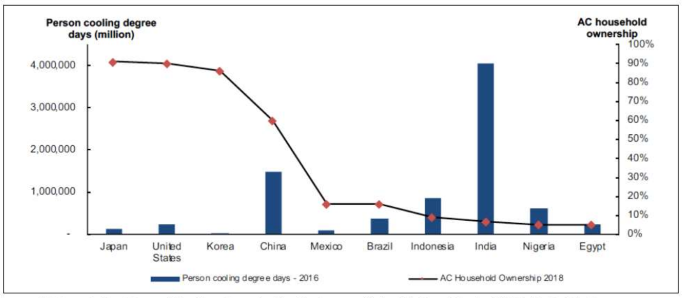
Antal apparater i DK



Kilde: Det Økologiske Råd

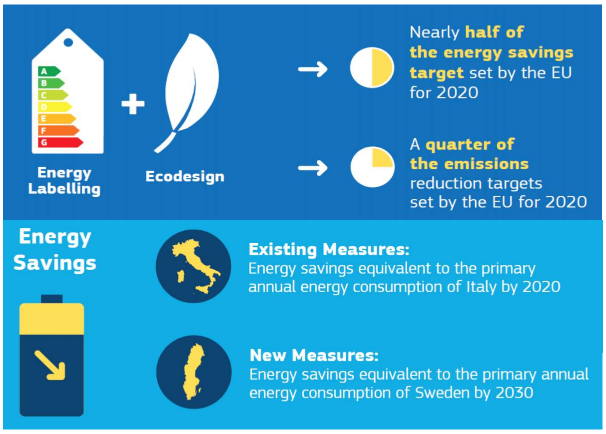
Hvorfor energibesparelser? Verdensbilledet

- Middelklassen i Asien og Stillehavs regionen forventes at vokse seks gange til 3,2 milliarder mennesker i 2030
- Forbrugskraften kan stige fra $ 5 billioner til $ 33 billioner



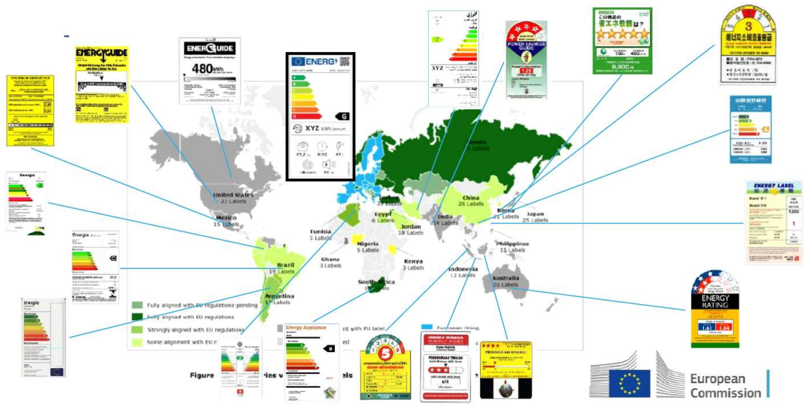
Source: IEA Report: The Future of Cooling: Opportunities for Energy-efficient Air Conditioning (2018); United Nations, Department of Economic and Social AffairsPopulation Division (2017); https://www.degreedays.net/

Virker Ecodesign og Energimærkning?



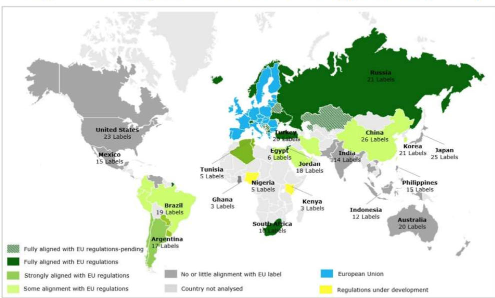
Kilde: European Commission

Energimærkning og ecodesign på verdensplan

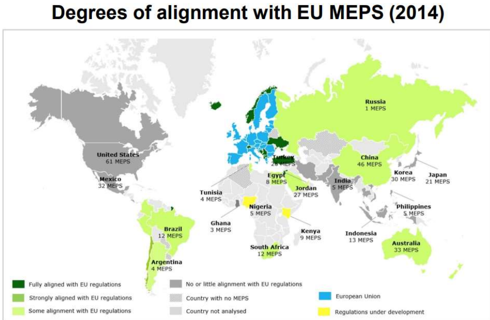


Energimærkning og ecodesign (MEPS) på verdensplan

Degrees of alignment with EU energy labels (2014)



Degrees of alignment with EU MEPS (2014)



MEPS = Minimum Energy Performance Standards

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Hvad er de nyeste tiltag? Indenfor ecodesign og energimærkning?

Info fra forordning for 2019/2024 "Krav til miljøvenligt design af køle/fryseapparater, der anvendes til direkte salg" der trådte i kraft 1. marts 2021.

- Tilgængelighed af visse reservedele i 8 år
- Maksimal leveringstid på reservedele 15 dage
- Let adgang til reparations- og vedligeholdelsesoplysninger på websiden for professionelle reparatører
- Krav til demontering til materialegenvinding og genbrug
- Informationskrav på gratis adgang til webside vedrørende f.eks.:
  - Temperaturindstillinger
  - De valgte temperaturindstillinger påvirker madspild
  - Rengøring og vedligeholdelse
  - Liste over professionelle reparatører

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Produktkategorier under revision

Link: https://www.eceee.org/ecodesign/

Ecodesign	Labelling	Product lot and study	Status in the EuP process
R	R	Space and combination heaters: 813/2013 and 811/2013 (ENER Lot 1)	Ecodesign and labelling regulations in force in September 2013.
		Professional refrigerating and freezing equipment: 2015/1095 and 2015/1094 (ENTR Lot 1)	Ecodesign and labelling requirements in force in August 2015.
R	R	Water heaters: 814/2013 and 812/2013 (ENER Lot 2)	Ecodesign and labelling regulations in force in September 2013.
		Distribution and power transformers: 548/2014 (ENTR Lot 2)	Revised ecodesign requirements published in October 2019.
R		PC:s and servers: 617/2013 (ENER Lot 3)	Proposal for revised requirements adopted. Scrutiny by the European Parliament and the Council period, until 17 January 2019.
		Sound and imaging equipment (ENER Lot 3)	Voluntary agreement on game consoles recognized in April 2015.
		Imaging equipment, Voluntary agreement (ENER Lot 4)	Voluntary agreement revised 2014 and implemented in January 2015.

Produktkategorier under revision:

- R Space and Combination heaters (813/2013 & 811/2013)
- R Water heaters (812/2013 & 814/2013)

Kilde: ECEEE

TEKNOLOGISK INSTITUT

Eksisterende forordninger under revision

Forordning	
811/2013	***Energimærkning*** af anlæg til **rumopvarmning** og **kombineret** brugsvands- og rumopvarmning
812/2013	***Energimærkning*** af **vandvarmere** og **varmtvandsbeholdere** inkl. pakker m. solvarme
813/2013	***Ecodesign krav*** til anlæg til **rumopvarmning** og **kombineret** brugsvands- og rumopvarmning
814/2013	***Ecodesign krav*** til **vandvarmere** og **varmtvandsbeholdere**

Ikrafttrædelse af nye forordninger forventes om 3-4 år

KOMMISSIONENS DELEGEREDE FORORDNING (EU) Nr. 811/2013
af 18. februar 2013
om supplering af Europa-Parlamentets og Rådets direktiv 2010/30/EU for så vidt angår energimærkning af anlæg til rumopvarmning, anlæg til kombineret rum- og brugsvandsopvarmning, pakker med anlæg til rumopvarmning, temperaturstyring og solvarmekomponent samt pakker med anlæg til kombineret rum- og brugsvandsopvarmning, temperaturstyring og solvarmekomponent

KOMMISSIONENS DELEGEREDE FORORDNING (EU) Nr. 812/2013
af 18. februar 2013
om supplering af Europa-Parlamentets og Rådets direktiv 2010/30/EU for så vidt angår energimærkning af vandvarmere og varmtvandsbeholdere samt pakker med vandvarmer og solvarmekomponent

KOMMISSIONENS FORORDNING (EU) Nr. 813/2013
af 2. august 2013
om gennemførelse af Europa-Parlamentets og Rådets direktiv 2009/125/EF for så vidt angår krav til miljøvenligt design af anlæg til rumopvarmning og anlæg til kombineret rum- og brugsvandsopvarmning

KOMMISSIONENS FORORDNING (EU) Nr. 814/2013
af 2. august 2013
om gennemførelse af Europa-Parlamentets og Rådets direktiv 2009/125/EF for så vidt angår krav til miljøvenligt design af vandvarmere og varmtvandsbeholdere

De nye forslag ifm. revision

– varmepumper og brugsvandsvarmepumper

Forordningen for Ecodesign krav dækker op til en nominel nytteeffekt på 1.000 kW

Primærenergifaktoren (CC) ændres
- Det er vedtaget at PEF reduceres fra 2,5 til 2,1
- Et udtryk for større andel af VE ved produktion af elektricitet på tværs af Europa

Testkonditioner for varmepumper
- MANGE diskussioner
- Brinetemperaturen for jordvarmepumper øges fra 0/-3 °C til 5/2 °C

Støj
- Støjgrænser bibeholdes
- Måling ved 54% kapacitet (testpunkt B) mod tidligere 35% (testpunkt C)
- Udetemperatur bibeholdes på +7 °C

De nye forslag ifm. revision

– varmepumper og brugsvandsvarmepumper

Circumvention (ikke tilladt)

- Omgåelse i testsituationer der foranlediger energibesparelser
- Software updates må ikke resultere i forhøjet energiforbrug

Monitorering

- Der skal måles og lagres data på anlæggets energiforbrug, varmeleverance, energieffektivitet, driftstid og antal on/off.
- Data skal gøres tilgængelig for *slutbrugeren* og *tredjepart*
- *Manual skal indeholde forslag til energioptimering*

Testtolerancer

- Præcisering af at disse kun bruges ifm. verificering af data
- Skærpelse for "alm." kedler

TEKNOLOGISK INSTITUT

De nye forslag ifm. revision

– varmepumper og brugsvandsvarmepumper

Rettidig omhu vil måske være at tage hånd om dette nu?

Krav til materialeeffektivitet

- **Reservedele** skal være tilgængelige på markedet for professionelle mindst 10 år efter et produkt kan købes.
- **Levering** af reservedele skal ske senest 15 arbejdsdage efter bestilling
- **Information om reparation og vedligehold** skal stilles til rådighed for professionelle aktører – en registreringsproces kan benyttes
- Produkter skal designes, så de kan **demonteres** med henblik på materialegenbrug og uden forurening.
- De professionelle aktører kan kræves **registreret** for at få adgang til information om reparation og vedligehold. Producenter og importører kan kræve at de professionelle aktører dokumenterer deres **kompetencer** inden registrering.

TEKNOLOGISK INSTITUT

De nye forslag ifm. revision
– varmepumper og brugsvandsvarmepumper

Minimumskrav Varmepumper

Nuværende forordning pr. 26. sept. 2017

Type	EEF η_s krav	SCOP omregning
MT luft-vand VP	110 %	2,83
LT luft-vand VP	125 %	3,20
MT jordvarme VP	110 %	2,95
LT jordvarme VP	125 %	3,33

Foreslået forordning 202X

Type	EEF η_s krav	SCOP omregning
MT luft-vand VP	130 %	2,79
LT luft-vand VP	155 %	3,32
MT jordvarme VP	130 %	2,90
LT jordvarme VP	155 %	3,42

Husk ny PEF/CC = 2,1

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De nye forslag ifm. revision
– varmepumper og brugsvandsvarmepumper

Energiklasserne

Nuværende

Energiklasse2	Årsvirkningsgrad η_s	Omregnet SCOP (L-V VP)
A+++	$\eta_s \geq 150$	SCOP ≥ 3,82
A++	$125 \leq \eta_s < 150$	3,2 ≤ SCOP< 3,82
A+	$98 \leq \eta_s < 125$	2,52 ≤ SCOP < 3,2
A	$90 \leq \eta_s < 98$	-
B	$82 \leq \eta_s < 90$	-
C	$75 \leq \eta_s < 82$	-
D	$36 \leq \eta_s < 75$	-
E	$34 \leq \eta_s < 36$	-
F	$30 \leq \eta_s < 34$	-
G	$\eta_s < 30$	-

Oplæg

Energiklasse	Årsvirkningsgrad η_s	Omregnet SCOP (L-V VP)
A	$\eta_s \geq 210$	SCOP ≥ 4,47
B	$180 \leq \eta_s < 210$	3,84 ≤ SCOP< 4,47
C	$150 \leq \eta_s < 180$	3,21 ≤ SCOP < 3,84
D	$120 \leq \eta_s < 150$	2,58 ≤ SCOP < 3,21
E	$100 \leq \eta_s < 120$	-
F	$90 \leq \eta_s < 100$	-
G	$\eta_s < 90$	-

Varmepumper med solvarme
Elektriske varmepumper
Gashybrid-VP
Kraftvarmeanlæg
Gas- & Oliekedler
El-kedler

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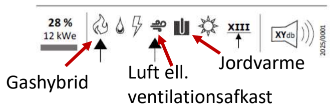
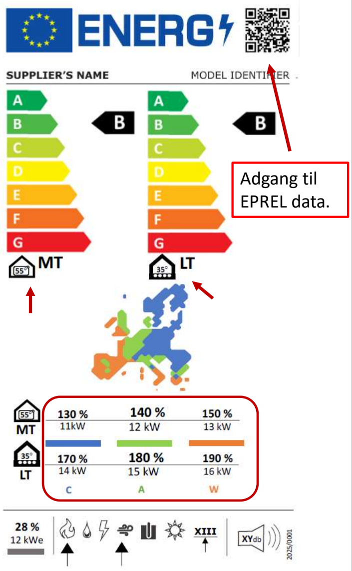
De nye forslag ifm. revision
– varmepumper og brugsvandsvarmepumper

Energimærkning – Varmepumper

- Energimærket viser virkningsgrader for både temperaturniveauet og klimazonen.
- Lavtemperatur (gulvvarme) og middeltemperatur (radiator) afspejles i piktogrammet. Høj temperatur er ikke vist, men kan hentes i oplysningsskemaet.
- Virkningsgrader og nominelle kapaciteter aflæses på mærket.
- Varmepumpetypen vises med pile på mærket





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Når nye Ecodesign- og Energimærkningsforordninger træder i kraft…
Hvad ser vi?

I starten:

- Når nye produktkategorier kommer under regulering, er produkterne på markedet er meget svingende kvalitet… … …
- Når regulativerne træder i kraft kommer dette til stadighed som en overraskelse for mange

Efter nogen tid:

- Ecodesign og Energimærkning bliver hverdag
- Alle spiller iht. de samme regler
- Vi ser nu at virksomhedernes formål (god markedspositionering) understøtter EU formål med introduktionen af Ecodesign og Energimærkning.
- Tidligere modstandere kalder nu på skrappere krav!

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Ecodesign og energimærkning med ”forbruger-briller” på

- **DU har magten!** Brug den!
- Energimærket gør det let for dig at vælge energieffektive produkter
- Let-forståelige oplysninger, letter kommunikationen med producent/installatør
- Du vil modtage standardiseret teknisk information fra alle producenter
- Markedsovervågningsmyndigheder (MSA'er) undersøger markedet

TEKNOLOGISK INSTITUT

Ecodesign og energimærkning med ”installatør-briller” på

- Nem standardiseret kommunikation mellem dig, producenten og slutbrugeren
- Nemt at sammenligne produkter
- Nem adgang til information og manualer via offentlige websteder
- Garanteret periode på specifikke reservedele i mindst otte år
- ”Let at reparere” er et krav i forordningen
- Adgang til reparations- og vedligeholdelsesoplysninger skal gives indenfor et døgn

Trådt i kraft for salgskølemøbler!
Forventes introduceret ifm. revision af resterende produktkategorier

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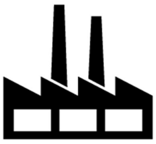
Ecodesign og energimærkning med "producent-briller" på

- Du kan nu promovere energieffektivitet!
- Standardiserede test betyder ens vilkår for alle producenter
- Standardiseret kommunikation letter kommunikationen med dine kunder
- Flere oplysninger om produkter vil blive tilgængelige online
- Let for dig at dokumentere og validere dine data



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EPREL - European Product Database for Energy Labelling

- Alle produktmodeller omfattet af energimærkning, som er markedsført efter 1. august 2017, skal registreres i EPREL.
- Databasen er med til at lette, men ikke erstatte det nationale markedsovervågningsarbejde idet alle produkter samles ét sted
- Testrapporter og den tekniske dokumentation kan kun ses af tilsynsmyndigheder
- Forbrugerne kan (kun) få adgang til databasen ved at scanne QR-koden på de nye energimærker (Pr. 1. marts 2021 for køleskabe og køle/fryseapparater med produkter til direkte salg)
- Udviklingen af EPREL er forsinket kan f.eks. pt. kan systemet kun generere produktdatablade på engelsk.

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Markedsovervågning

~~"Det er guddommeligt at fejle"~~

~~*Citat: Rane Willerslev*~~

Ikke når det kommer til at overholde ecodesign og energimærkningskrav!

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Markedsovervågning

- Sikkerhedsstyrelsen er markedsovervågningsmyndighed (MSA – Market Surveillance Authority) i Danmark indenfor køl/frys.
- Markedet for varmepumper, chillere, CDU'er, salgskølemøbler, professionelle kølemøbler testes jævnligt grundet :
  - Voksende marked
  - Nationale interesser/stort hjemmehørende industri
  - Historien er ikke særlig prangende… … …
- Nationale krav til markedsovervågning ens på tværs af EU
- MSA'er tester også kommende og "nye" produktkategorier under regulering

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Markedsovervågning

- Cross-border inspections - Den nye markedsovervågningsforordning har givet værktøjer, som styrker samarbejdet på tværs af grænserne
- Øget fokus på varer fra 3. verdenslande og øget samarbejde med toldmyndighederne
- En tendens til at samarbejde i større testprojekter (F.eks. via EEPliant)
- Bedre samarbejde gennem ICSMS (Information and Communication System on Market Surveillance)
  - MSA'erne forpligtet til at registrere alle produkter som ikke har bestået kontrollen
  - Sikkerhedsstyrelsen registrerer alle produkter uanset udfaldet af kontrollen
  - Det er svært at "skjule" sig på EU-markedet

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Markedsovervågning

- I gennemsnit består 15% af produkter testet i DK ikke. Dette harmonrer med Europa Kommissionens estimat på, at 10-20 % af produkterne på markedet ikke opfylder kravene

Hvad er konsekvensen ved non-compliance?

- Straffen skærpet væsentligt
- Bødetakster skærpet
- DNS blokering af hjemmeside

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Spørgsmål?

Esben Vendelbo Foged
Sektionsleder ved Køle- og Varmepupeteknik

E-mail: EVF@teknologisk.dk

Tlf.: (+45) 72202046

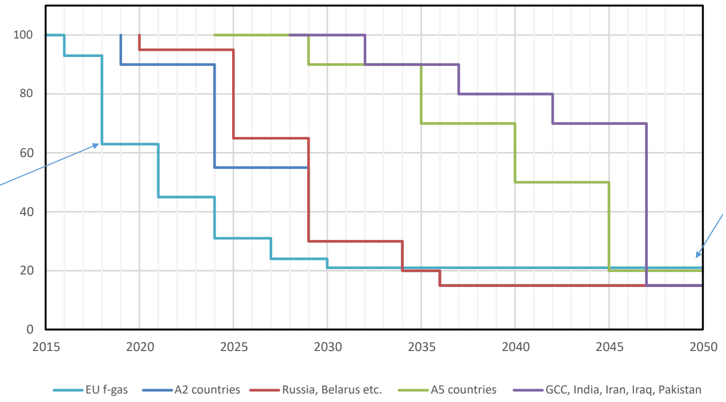
Køle- og Varmepumpeforum 2021

4/10-2021
Kølemidler, næste skridt

Asbjørn Vonsild, Vonsild Consulting ApS
vonsild@vonsild-consulting.com

Global phase down of HFC

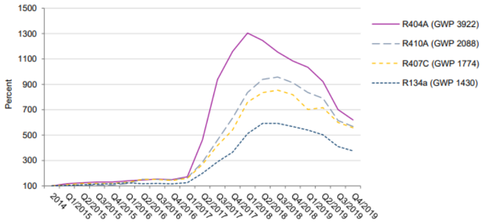
EU F-Gas regulation and the Montreal Protocol (with Kigali amendment)



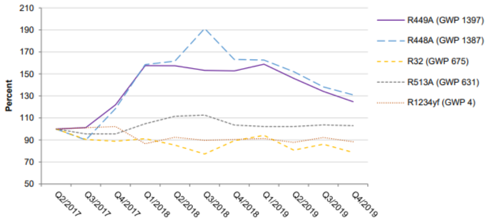
Phase down is global but EU is leading, and Denmark has been leading in the EU

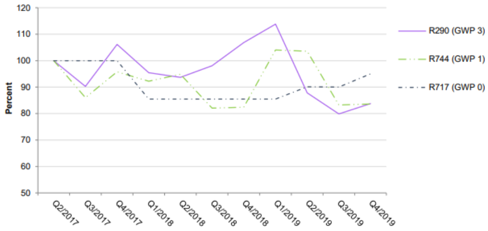
Estimated to avoid ½ °C of global warming

Pris på HFC og alternativer



Kilde: European Commission, Report from the Commission on the availability of hydrofluorocarbons on the Union market, Brussels, 16.12.2020 C(2020) 8842 final





Addressing climate impact of refrigerants:

1. Refrigerant manufactures attempt to lower GWP (the climate impact of) their refrigerants
   - New refrigerants and trade-offs
   - HFO with 3 or more carbons, low GWP, TFA, and R-23(?)
   - HFO with 2 carbons, low GWP, flammability, toxicity
   - R-13I1 low GWP, low/no flammability, ozone depletion, stability, toxicity
   - Naturals, low GWP, toxicity, flammability, pressure

2. Safety standards are updated to allow more use of new and old alternatives
   - Charge increase
   - Complexity increase

New refrigerants

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År	Kølemiddel
2008	434A, 435A, 510A, 436A, 436B, 437A.
2009	**1234yf**, 433B, 433C, 438A.
2010	407F, 417B.
2011	439A, 440A, 441A, **1234ze(E)**, 511A.
2012	512A, 442A, 443A.
2013	**444A**, 417C, **445A**, 419B, 422E.
2014	**1233zd(E)**, **446A**, **447A**, **448A**, **449A**, **450A**, **444B**.
2015	**451A**, **451B**, **513A**, **452A**, 453A, **1336mzz(Z)**, **449B**, **454A**, **454B**.
2016	407G, **455A**, **513B**, **454C**, **449C**, **1130(E)**, **514A**, **515A**, **447B**, **452B**, **456A**, **457A**, **452C**, 458A.
2017	**459A**, **459B**, **460A**, **460B**, 407H, 461A, **516A**, **1224yd(Z)**, 462A, **1132a**.
2018	**463A**, **460C**, **464A**, 407I, **465A**, 436C.
2019	**1336mzz(E)**, 13I1, 427B, 466A, 467A, **468A**, 469A, **470A**, **515B**.
2020	470B, **471A**, 472A, **457B**.
2021	**473A**, **448B**, 427C. At least 9 others are underway including new blends with with 1132(E) og med 1132a.

Key:
Blend with HFO
Pure med HFO/HCFO/HCO

Refrigerant safety class

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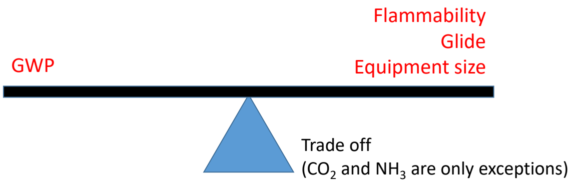
- This presentation focusses on flammability:

Flammability ↑

Higher flammability	**A3:** Hydrocarbons	**B3:** No refrigerants
Flammable	**A2:** R152	**B2:** Seldomly used
Lower flammability	**A2L:** Most HFO's, R32	**B2L:** Ammonia
No flame propagation	**A1:** CFC, HCFC, most HFC's	**B1:** R123
	Lower toxicity	**Higher toxicity**

New refrigerants in general

- Most new refrigerants matches existing in pressure and temperature
- So many new refrigerants because every company needs their own patented alternative to each of the traditional HFC's
- Most new refrigerants are mixtures of the same pure substances: R32, R134a, R125, R1234yf, 1234ze
- There are no ideal refrigerant, not even in theory. All possible chemical combinations have been checked!



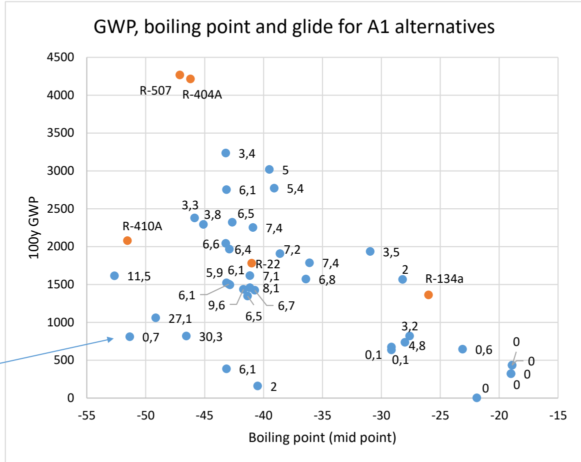
Flammability class and GWP

- Refrigerants with ASHRAE numbers given since 2010 have been analysed in the below
- GWP is plotted against boiling point, with the glide indicated for each refrigerant

- Glide: Difference between boiling point and dew point.
  Example: Whiskey is a mix of water and ethanol (a small fraction of tasteful impurities). It starts boiling around 80 C, but the last drop evaporates around 100 C, giving a glide of: 100-80=20 K

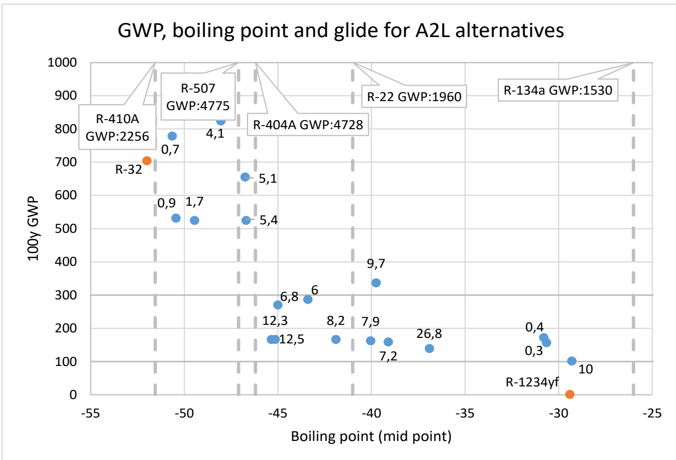
Non-flammable options (since 2010)

- HFO's have enabled lowering GWP
- R-13I1 (CF_3I) can potentially lower GWP further.
  - Example: 466A



A2L flammable options (since 2010)

- Same pattern, but much lower GWP…
- Note:
  - 404A options have glide
  - 410A options have GWP from just below 500 to just above 700.



Concerns related to HFO's of the 1200 and 1300 series

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These HFO's all have a CF_3 group connected with a central carbon with either an F or an H attached.

A rough statement:

- When the central carbon has an F the HFO generates TFA
- When the central carbon has an H the HFO is suspected of generating R-23

Central carbon with F:
1234yf: CF_3-CF=CH_2
1224yd: CF_3-CF=CHCl

Central carbon with H:
1234ze: CF_3-CH=CHF
1233zd: CF_3-CH=CHCl
1336mzz(Z): CF_3-CH=CH-CF_3
1336mzz(E): CF_3-CH=CH-CF_3

TFA - Trifluoroacetic acid

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- TFA is causing concern as a break down product of several refrigerants (and insecticides), especially HFO-1234yf
- TFA is a very strong acid, highly soluble in water, but with relatively low toxicity
- There are no known break-down processes of TFA in nature
- TFA can accumulate in soil, plants, and fresh water, and has been found in ground water in Denmark
- TFA is occurring naturally in the oceans, but not in fresh water
- TFA is generated locally from HFO's
- TFA is **not currently** considered to be a problem… more on TFA in the next talks on the agenda!

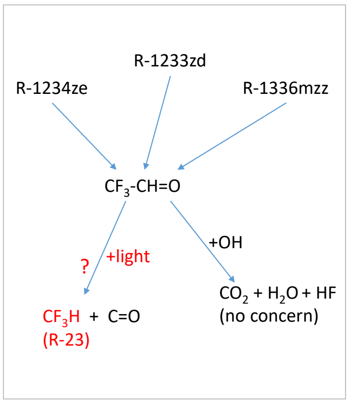
R-404A is 52% R-143a

Refrigerant	Fraction that becomes TFA	Source of data
R-134a	21%	Solomon K, Velders G, Wilson S, Madronich S, Longstreth J, Aucamp P, Bornman J., "Sources, fates, toxicity, and risks of trifluoroacetic acid and its salts: Relevance to substances regulated under the Montreal and Kyoto protocols". Journal of Toxicology and Environmental Health B, 2016.
R-143a	100%	
R-1234yf	100%	
R-1234ze(E)	Less than 10%	Javadi MS, Søndergaard R, Nielsen OJ, Hurley M, Wallington T., "Atmospheric chemistry of trans-CF_3CH=CHF: Products and mechanisms of hydroxyl radical and chlorine atom initiated oxidation. Atmos Chem Phys 8:3141-3147", 2008.
	0%	T.J. Wallington, M.P. Sulbaek Andersen, O.J. Nielsen, "Atmospheric chemistry of short-chain haloolefins: Photochemical ozone creation potentials (POCPs), global warming potentials (GWPs), and ozone depletion potentials (ODPs)", Chemosphere 129 (2015) 135–141, 2015 *
R-1233zd(E)	0%	
R-1233zd(Z)	0%	
R-32	0%	Due to chemical composition

*TFA production is not the primary topic of the Wallington, 2015 paper, and it gives no references or arguments as to where this data comes from.

HFC-23

- Early 2020 Australian researchers shared a draft paper that R-1234ze(E) creates 11% R-23 as a breakdown product.
- This goes against the traditional understanding of the breakdown process
- R-23 has GWP = 14600 and even a small R-23 generation would be a problem
- The paper has been refused in a peer review journal. Probably due to too little evidence of the amount of R-23 generated
- Conclusion:
  - R-23 is probably generated in some amount, because it is theoretically possible, but unclear how much.
  - If the amount generated is < 1%, then it is not a problem, if it is >10% then it is a problem.



HFO's of the 1100 series

- HFO's in the 1100 series have 2 carbons with a double bond (C=C) and 4 H, F, or Cl atoms.
- Currently there are only two of these approve by ISO 817/ASHRAE 34:
  - R-1130(E) : CHCl=CHCl (safety class B1)
  - R-1132a: CH_2=CF_2 (safety class A2)
- Due to the low number of F or Cl atoms, the break-down products are simple and not of concern
- Currently HFO's in the 1100 series are either flammable or toxic
- These small molecules are prone to polymerize, and probably require a stabilizer added to the refrigerant mixture to keep stable in the system

CF_3I, R-13I1 – Game changer?

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- Honeywell have resently proposed a new low GWP molecule and a non-flammable blend (R466A) to replace 410A
- The new molecule is CF_3I, also known as IFC-13I1, or R-13I1 (or Freon 13I1), a molecule used for fire extingising.
- Using CF_3I in blends enables lowering the GWP without increasing flammability
- R466A contains CF_3I and is new non-flammable R410A alternative with GWP just below 750 and almost no glide.

It sounds great!

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- When a non-flammable 410A can be made below GWP 750 then
  - 404A altertives may be at GWP 200, and
  - 134a below 50?
- Flammability has been the biggest challenge of reducing GWP!
- ODP in Europe is estimated to be 0.0034 (WMO, 2014), too low to worry!
- Looks like a technical revolution ready to happen!

But…

- CF_3I has been considered before, and deselected by the industry
- CF_3I is known to be unstable, breakdown products are highly toxic and corrosive. Stabilizer needs to be added to the refrigerant.
- CF_3I does have some toxicity. Possibly mutagenic.
- CF_3I and R466A are only approved as refrigerants in the US
- The GWP of R466A is still too high for most applications in the long run.
- ODP near equator is higher than R-22 (ODP in India is 0.09, while R-22 is 0.03)
- CF_3I is allowed in EU, but is on a special EU list requiring reporting

Natural refrigerants

Natural refrigerants are nothing new:
- Ammoniak
- Hydrocarbon (f.eks. propane, propene, iso-butane, ethan)
- Kuldioxid (CO_2)
- Vand
- Luft

These refrigerants have very low impact on the environment, but each come with it's own challenges. Where they are good, they are very good, but nothing fits everywhere!

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Safety standards are being updated to allow more use of new and old alternatives

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Updating safety standards

Mainly regarding flammability, but Toxicity definitions are also being revisited.

All major safety standards are being updated to allow higher charges of flammable refrigerants:

- IEC 60335-2-40, increase charges in smaller rooms. Publication planned for 2022.
- IEC 60335-2-89, increased to approx. 500g of A3 and 1,2 kg of A2L. EN version underway.
- EN 378, copy methods from the above standards. Publication planned for 2024.
- ISO 5149, copy methods from the above standards. Publication planned for 2024.

Revision of toxicity definition in ISO 817 is also being considered (ISO/TC86/SC1/TF2)

Philosophy behing larger charges

- To maintain safety: Larger refrigerant charges are combined with higher requirements for safety in system design
- Not all safety measures are practical for all designs (e.g. air-flow is impractical for water-to-water systems), so
  - Standards have a cataloque of safety measures, each with a different charge allowance
  - Examples: Dilution by gravity, air circulation, ventilation, safety shut-off valves, alarms, additional tightness requirements, surrounding concentration test.
- Due to urgency, not all options gets into all standards!
- Complexity increases!

Example: IEC 60335-2-40 for A/C and HP

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- Mitigation measures:
  - dilution by gravity,
  - air circulation,
  - ventilation,
  - safety shut-off valves
  - but **not** surrounding concentration test
- Process srarted in 2015, publication in 2022 as IEC
- **EN** 60335-2-40 likely to follow in 2024/25

-2-40 Ed. 7 — Split systems with R290

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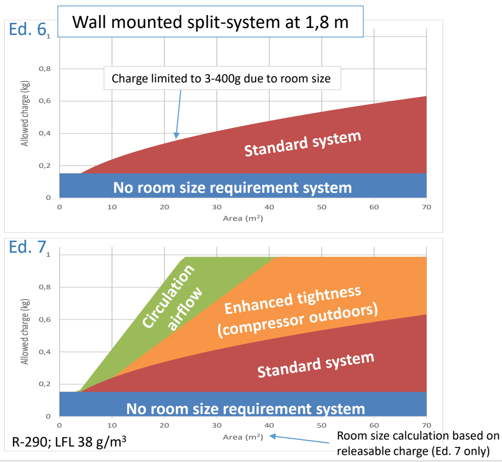
- Wall mount split, options:
  - Limit without room size (no change)
  - Limit for traditional tightness and no airflow (same as current limits)
  - Limit for traditional tightness with airflow
  - Limit for enhanced tightness and no airflow
  - Limit for enhanced tightness with airflow
- Releasable charge

Options can be combined. An example:

- traditional tightness with airflow is used for the ”compressor on” condition, while
- releasable charge can be combined with traditional tightness and no airflow for the ”compressor off” condition.

- Allowed charge doubled for most systems

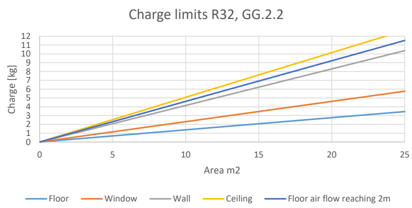


-2-40 Ed. 7 — Large commercial split systems with A2L

There are three options, and a free choice:

- Option 1: Enhanced tightness, GG.10, with airflow (see also example on RTU slide).
- Option 2: GG.1, Charge limit in very small rooms: 6 × LFL. For R-32: 1,84 kg
- Option 3: GG.2.2, Charge in small rooms with airflow. Upper limit 15,96 kg (see also example on B/W monoblock slide).

The charge limit is per circuit, and each room is evaluated independently for multi-splits. Options 2 and 3 can be combined with releasable charge concept.



Option 1 with airflow:

Allowed charge:	50% × V × LFL	75% × V × LFL	# Evap × 15,96 kg
Above ground	No measures		One measures + alarm: • SSV(75%) + alarm • Ventilation + alarm
Below ground	No measures	One measure: • Ventilation • SSV(50%) • Alarm	Not allowed

Room size	Below ground no measures	Above ground no measures or Below ground 1 measure
10 m²	3,37 kg	6,75 kg
20 m²	6,75 kg	10,13 kg
30 m²	15,19 kg	15,19 kg
50 m²	1 unit: 15,96 kg 2 or more units: 16,88 kg	1 unit: 15,96 kg 2 or more units: 25,32 kg
100 m²	1 unit: 15,96 kg 2 units: 31,92 kg 3 or more units: 33,77 kg	1 unit: 15,96 kg 2 units: 31,92 kg 3 units: 47,89 kg 4 or more units: 50,65 kg

Conclusion

- Global HFC phase down addressed by
  - New refrigerants
  - Updated safety standards (for new refrigerants and naturals)
- There is a trade-off for new refrigerants:
  - Lower GWP gives higher flammability or higher glide or lower capacity
- New refrigerants brings risk of new problems, while old refrigerants brings known old problems
- No refrigerant is ideal
- All major safety standards are being updated to allow for more flammable refrigerant
- Charge limits become a catalogue of options, but not all options gets into all standards
- Complexity increases
- Standardisation is a slow process!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Risk & Policy Analysts

Environmental and Health effects of HFO refrigerants

Presentation to
7th International Symposium on Advances in Refrigeration and Heat Pump Technology 2021

Max La Védrine
Senior Consultant

4 October 2021

RPA
Risk & Policy Analysts

Introduction – importance of refrigeration

- Refrigeration is critically important to society:
  - Food security
  - Health security
  - Comfort
- There is less refrigeration in developing countries, which are typically hotter, but this is changing
- There are ca. 3 billion refrigeration, air-conditioning and heat pump systems in operation worldwide and the refrigeration sector (including air conditioning) consumes about 17% of the overall electricity used worldwide (International Institute of Refrigeration, 2015)
- Refrigeration contributes to global greenhouse emissions through energy consumption and release of emissions
- Greater energy efficiency and reduced energy use is required
- Reducing leakage and transitioning to lower Global Warming Potential (GWP) will likely be important

2

RPA Risk & Policy Analysts

Introduction – our past study

Acknowledgements

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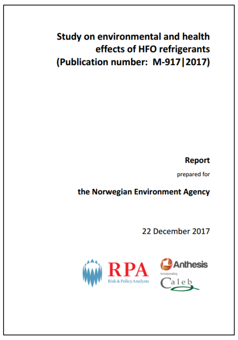
  - David Fleet; Max La Védrine (RPA); Dr James Hanlon; Dr Kate Osborne (formerly RPA)
  - Paul Ashford (Anthesis-Caleb)
  - Sandrine Bernard; Ole-Kristian Kvissel; Marit Kopangen (Norwegian Environment Agency)
  - http://www.miljodirektoratet.no/en/News1/2018/Study-on-environmental-and-health-effects-of-HFO-refrigerants/


Study on environmental and health effects of HFO refrigerants (Publication number: M-917|2017)

Report

prepared for

the Norwegian Environment Agency

22 December 2017

RPA Anthesis Caleb

3

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Norwegian Environment Agency Study

Aims of the study

- Study on HFO and degradation products
  - Assessment of HFOs used as refrigerants
  - Assessment of chemical process and degradation products
- Environmental and health effects
  - Environmental effects of HFOs
  - Hazards to health
- Effect of future emissions on the environment
  - Calculate future emissions of HFOs
  - Risk assessment of HFOs in the future

4

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Methodology

- Literature review and consultation
  - The academic and grey literature were reviewed
  - Consultation undertaken with selection of stakeholders
- Projected emissions
  - Technology and Economic Assessment Panel (TEAP) - Task Force Update Report (Sept 2016) used as a starting point
  - BUA (Business as Usual) and Mitigation 5 scenario (MIT-5) have been used
- Risk Assessment
  - Performed using EUSES software
  - TFA has been modelled in the risk assessment
- Presented at IIR International Conference on the Application of HFO Refrigerants

5

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Natural refrigerants used

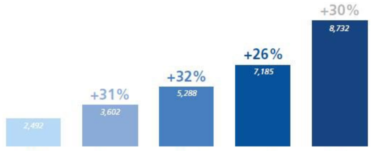
Natural refrigerants:

- Carbon dioxide (CO_2) (R-744);
- Hydrocarbons (R-290 (propane); R-1270 (propylene), and R-600a (isobutane))

Witnessing a high rate of adoption by major superstore and food retail chains in the European and North American regions.

The GWP of CO_2 is 1, however, a challenge for CO_2 has been the high pressure needed for operation.

Hydrocarbons have a flammability issue and although they do not have a zero GWP, they are still very low compared to HFCs. Ammonia (R-717) is also a natural refrigerant with a GWP of zero, although care needs to be taken due to its toxicity.



Growth of CO_2-based stores in the EU, Norway and Switzerland (estimate value for 2016)
Source: Jan Dusek, Shecco. Available at: http://www.atmo.org/presentations/files/5907fb91732731493695377MljnG.pdf

6

HFOs currently used

- A selection of HFO substances
  - HFO-1234yf is the most common HFO used
    - Replacement for HFC-134 in mobile air conditioning
  - HFO-1234ze and HFO-1233zd also used as refrigerants
  - HFO-1244yd and HFO-1336mzz could also be used
- A selection of HFO blends
  - A number of HFO/HFC blends have been identified including:
    - R-448a (Solstice® N40)
    - R-449a (Opteon™ XP40)
    - R-450a (Solstice® N13)
    - R-452a (Opteon™ XP44)
  - Blends are high purity
  - The blends above contain HFO-1234yf and/or HFO-1234ze

7

Environmental effects from HFOs

- Environmental impacts - TFA
  - Trifluoroacetic acid (TFA) is the main degradation product of HFO-1234yf (1:1)
  - Other degradation products include formic acid, carbon dioxide, hydrofluoric acid and hydrochloric acid
  - TFA: highly persistent and readily forms trifluoroacetate salts
  - Accumulation of TFA in terminal sinks such as playas, salt lakes and oceans
  - Some missing information on the toxicity of TFA on organisms
  - Hydrofluoric acid (another by-product) will be rapidly neutralised by water

8

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Ecotoxicological data - TFA

Table 8-15: Freshwater aquatic organisms	
Species	**LC_{50} / NOEC concentration (mg/L)**
Zebrafish (*Danio rerio*) (fish)	>1,200 mg/L/ 1,200 mg NaTFA salt/L
Water fleas (*Daphnia magna*) (crustacean)	>1,200 mg/L (EC_{50}) / 1,200 mg NaTFA salt/L
Pseudokirchneriella subcapitata (algae)*	0.62 mg/L (EC_{50}) TFA#
Note:*Known as *Raphidocelis subcapitata* and *Selenastrum capricornutum* also	

Table 8-17: Fresh water toxicity to algae (mg/L)

Endpoint	Most toxic	Average value (range)	Median	Least toxic
EC_{50}	0.62	441 (0.62 – 1997)	99	1997
NOEC	0.1	275 (0.1 – 999)	98	999

Table 8-18: Marine water toxicity to algae (mg/L)

Endpoint	Most toxic	Average value (range)	Median	Least toxic
EC_{50}	>97	732 (97 – 1997)	103	1997
NOEC	97	732 (97 – 1997)	103	1997

9

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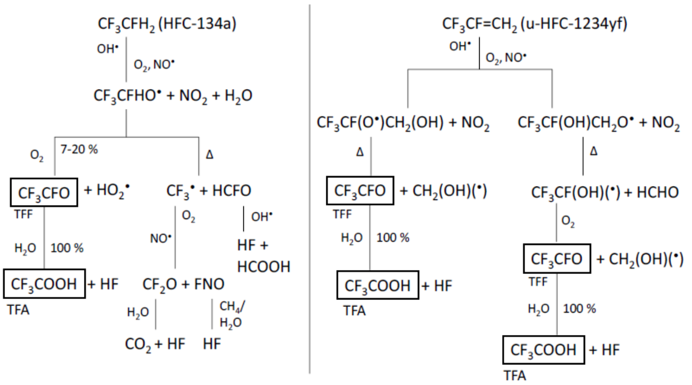
Atmospheric degradation



Source: own research, Öko-Recherche

10

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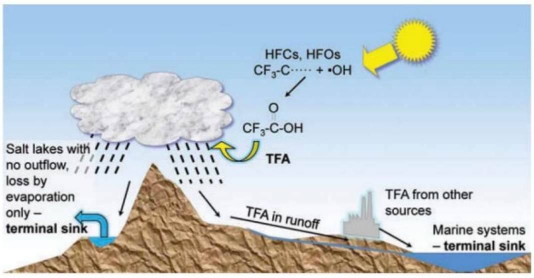
Environmental effects from HFOs

Environmental fate of TFA



The fates of TFA and its salts in the environment
Source: Solomon et al (2016): Sources, fates, toxicity, and risks of trifluoroacetic acid and its salts: Relevance to substances regulated under the Montreal and Kyoto Protocols. Journal of Toxicology and Environmental Health Part B., 19, pp 289-304

11

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Health impacts

- Human health
  - HFOs are asphyxiant in high concentrations and that contact with the evaporating liquid may lead to freezing of the skin or frostbite
  - HFO-1234yf is considered to be low hazard for inhalation exposure, dermal exposure and eyes
  - Occupational Exposure Levels (OELs) of 800 ppm (400 ppm for an 8 hour time weighted average) for HFOs generally and for HFO-1234ze, the OEL is 1000 ppm
  - Refrigeration workers in the EU who handle HFO refrigerants are also subject to the requirements of the F gas regulations
  - Limited information in the literature

12

CLP classification

Summary of Classification and Labelling

Harmonised classification - Annex VI of Regulation (EC) No 1272/2008 (CLP Regulation)

General Information

Index Number	EC / List no.	CAS Number	Interna
607-091-00-1	200-929-3	76-05-1	trifluoroacetic acid . . . %

ATP Inserted / Updated: CLP00
CLP Classification (Table 3)

Classification		Labelling		
Hazard Class and Category Code(s)	Hazard Statement Code(s)	Hazard Statement Code(s)	Supplementary Hazard Statement Code(s)	Pictograms, Signal Word Code(s)
Skin Corr. 1A	H314	H314		GHS05 GHS07 Dgr
Acute Tox. 4 *	H332	H332		
Aquatic Chronic 3	H412	H412		

Signal Words	Pictograms
Danger	 Corrosion, Exclamation mark

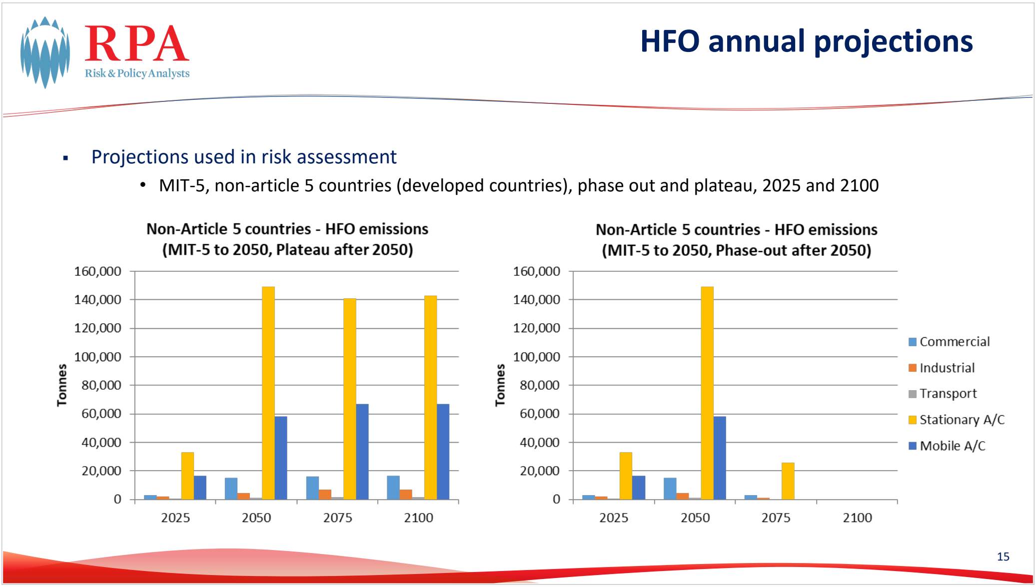
https://echa.europa.eu/information-on-chemicals/cl-inventory-database/-/discli/details/47316

13

HFO projections

- Scenarios
  - Emissions were projected for two scenarios
    - Business As Usual (BAU)
    - Mitigation 5 (MIT-5)
  - For each scenario plateauing and phasing out of HFO emissions was projected after 2050
- Sectors
  - Emissions were predicted for five sectors, these were;
    - Commercial
    - Industrial
    - Transport
    - Stationary air conditioning
    - Mobile air conditioning

14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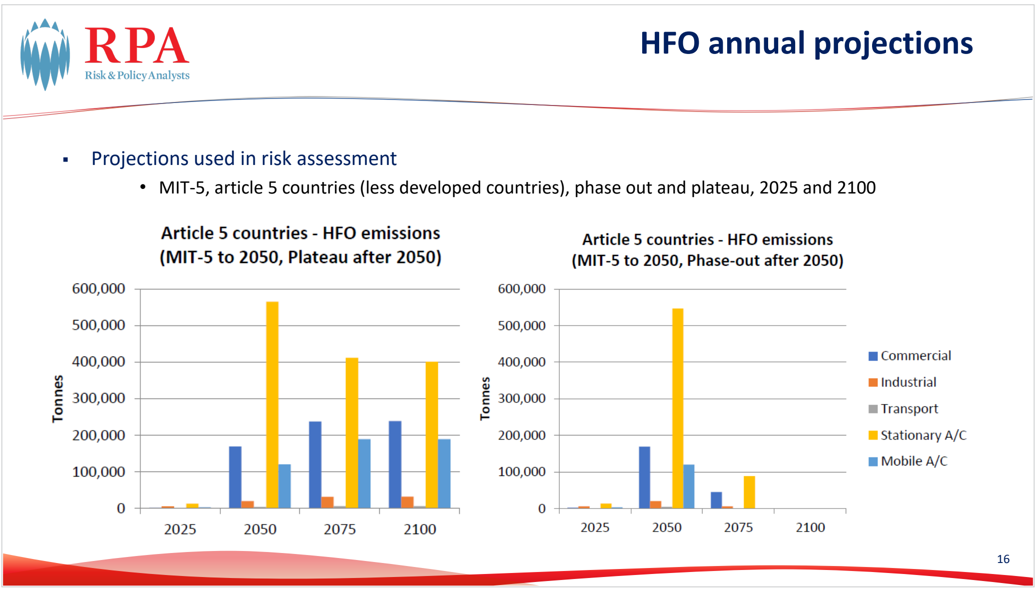
HFO annual projections
Projections used in risk assessment
MIT-5, non-article 5 countries (developed countries), phase out and plateau, 2025 and 2100
Non-Article 5 countries - HFO emissions
(MIT-5 to 2050, Plateau after 2050)
Non-Article 5 countries - HFO emissions
(MIT-5 to 2050, Phase-out after 2050)
Tonnes
160,000
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
2025
2050
2075
2100
Commercial
Industrial
Transport
Stationary A/C
Mobile A/C
15


RPA
Risk & Policy Analysts
HFO annual projections
Projections used in risk assessment
MIT-5, article 5 countries (less developed countries), phase out and plateau, 2025 and 2100
Article 5 countries - HFO emissions
(MIT-5 to 2050, Plateau after 2050)
Article 5 countries - HFO emissions
(MIT-5 to 2050, Phase-out after 2050)
Tonnes
600,000
500,000
400,000
300,000
200,000
100,000
0
2025
2050
2075
2100
Commercial
Industrial
Transport
Stationary A/C
Mobile A/C
16

HFO projections

- Projections used in risk assessment
  - MIT-5, non-article 5 countries (developed countries), phase out and plateau, 2025 and 2100

Non-Article 5 countries - HFO emissions (MIT-5 to 2050)								
					HFO Annual Emissions (tonnes)			
Scenario	Sector	Equipment Life (years)	HFO Allocation (%)	Emissions Rate/year (%)	2025	2050	2075	2100
Plateau after 2050	Commercial	30	50	15	3,129	15,336	16,211	16,526
	Industrial	30	20	10	1,909	4,329	6,912	7,003
	Transport	15	50	30	421	1,256	1,375	1,375
	Stationary A/C	30	50	25	32,963	149,354	140,699	142,656
	Mobile A/C	15	50	35	16,502	58,365	67,025	67,025
	Total				**54,923**	**228,641**	**232,222**	**234,585**
Phase-out after 2050	Commercial	30	50	15	3,129	15,336	2,884	0
	Industrial	30	20	10	1,909	4,329	1,265	0
	Transport	15	50	30	421	1,256	0	0
	Stationary A/C	30	50	25	32,963	149,354	25,653	0
	Mobile A/C	15	50	35	16,502	58,365	0	0
	Total				**54,923**	**228,641**	**29,802**	**0**

17

EU-28 demand and emissions increase 2010-2050
(German Environment Agency, UBA)

Table 23: Demand and emissions of HCFCs, HFCs, u-HFCs and u-HCFCs in Europe (EU-28) in metric tons from 2000 to 2050 in 10-year steps across all sectors for the "u-HFC and u-HCFC maximum scenario".

Year	2000	2010	2020	2030	2040	2050
Demand	**45,138**	**90,409**	**95,969**	**93,338**	**91,264**	**91,756**
Mobile air conditioning	18,116	28,427	31,616	32,264	32,413	32,361
Stationary air conditioning	3,447	20,459	25,028	24,059	23,412	23,314
Refrigeration	10,002	17,815	16,825	14,417	12,742	13,190
Foams	6,686	13,933	13,261	13,303	13,316	13,316
Propellants, solvents and fire extinguishing agents	6,860	9,748	9,212	9,268	9,354	9,548
Others (semiconductor industry only)	27	27	27	27	27	27
Emissions	**25,597**	**56,606**	**60,859**	**62,825**	**64,524**	**66,554**
Mobile air conditioning	7,187	23,983	29,466	31,889	33,017	33,856
Stationary air conditioning	1,030	7,799	12,193	14,189	15,533	16,208
Refrigeration	4,510	13,253	8,736	6,487	5,028	4,777
Foams	6,584	6,277	5,074	4,829	5,505	6,125
Propellants, solvents and fire extinguishing agents	4,633	5,051	5,187	5,228	5,238	5,385
Others (semiconductor industry and HFC production)	1,653	243	203	203	203	203

18

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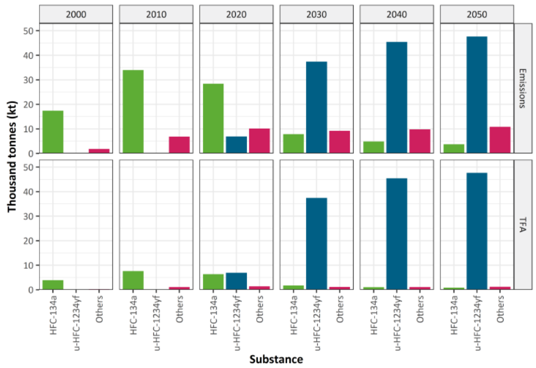
EU-28 total and TFA emissions
(German Environment Agency, UBA)

Figure S 3: Trends of European emissions (EU-28) and resulting TFA quantities formed by relevant HFCs, u-HFCs and u-HCFCs used as refrigerants and blowing agents in various applications in kilotonnes in the period from 2000 to 2050. All other projected substances that form TFA are summarized as "Others".



Source: own research, Öko-Recherche

19

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EU-28 emissions 2018-2050
(German Environment Agency, UBA)

Table 44: Projected amount of trifluoroacetic acid (TFA) from the atmospheric degradation of halogenated substances emitted in Europe (EU-28) in tonnes for different years from 2018 to 2050 (based on emission data from the modelling in Chapter 3). The TFA totals and the percentage share of the different refrigerants and blowing agents in the total amount are shown. In addition, the percentage increase of the TFA total quantity as well as the individual substances or substance groups in relation to 2018 is shown. "Other" includes all substances projected in Chapter 3 except HFC-134a and u-HFC-1234yf.

Sector	2018	2020	2030	2040	2050
Total TFA quantity in t from EU-28	**11,952**	**14,650**	**40,363**	**47,691**	**49,718**
HFC-134a	60 %	43 %	4 %	2 %	2 %
u-HFC-1234yf	29 %	47 %	93 %	95 %	96 %
Others	11 %	10 %	3 %	2 %	2 %
Increase in relation to 2018		**23 %**	**238 %**	**299 %**	**316 %**
HFC-134a		-11 %	-75 %	-85 %	-88 %
u-HFC-1234yf		98 %	976 %	1,207 %	1,270 %
Others		7 %	-10 %	-13 %	-6 %

20

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Views from industry
(Andy Pearson, Star Refrigeration Ltd)

- Important refrigerant considerations:
  - Cost of the refrigerant (or system)
  - Efficiency
  - Operating pressure
  - Cooling capacity
  - Ozone Depletion Potential
  - Global Warming Potential
  - Toxicity
  - Flammability

21

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Views from industry
(Andy Pearson, Star Refrigeration Ltd)

- Important refrigerant considerations:
  - Cost of the refrigerant (or system)
    - Purchase price of refrigerant for contractors
    - Scoring adjusted to present day values
    - Price hikes excluded
  - Efficiency
  - Operating pressure
  - Cooling capacity
  - Ozone Depletion Potential
  - Global Warming Potential
  - Toxicity
  - Flammability

22

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Views from industry
(Andy Pearson, Star Refrigeration Ltd)

- Important refrigerant considerations:
  - Cost of the refrigerant (or system)
  - Efficiency
    - In theory all refrigerants should give similar levels of efficiency in a Perkins vapour compression cycle
    - Any differences are due to secondary effects:
      - Pressure loss in key components
      - Amount of flash gas
      - Critical temperature
  - Operating pressure
  - Cooling capacity
  - Ozone Depletion Potential
  - Global Warming Potential
  - Toxicity
  - Flammability

23

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Views from industry
(Andy Pearson, Star Refrigeration Ltd)

- Important refrigerant considerations:
  - Cost of the refrigerant (or system)
  - Efficiency
  - Operating pressure
    - Operating pressure is typical the opposite of capacity
  - Cooling capacity
  - Ozone Depletion Potential
  - Global Warming Potential
  - Toxicity
  - Flammability

24

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Views from industry
(Andy Pearson, Star Refrigeration Ltd)

- Important refrigerant considerations:
  - Cost of the refrigerant (or system)
  - Efficiency
  - Operating pressure
  - Cooling capacity
    - High pressure refrigerants give higher capacity per unit of compressor volume
    - In large systems this correlates well with system cost as compressors, pipe sizes and heat exchangers tend to be smaller
  - Ozone Depletion Potential
  - Global Warming Potential
  - Toxicity
  - Flammability

25

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Views from industry
(Andy Pearson, Star Refrigeration Ltd)

- Important refrigerant considerations:
  - Cost of the refrigerant (or system)
  - Efficiency
  - Operating pressure
  - Cooling capacity
  - Ozone Depletion Potential
    - The refrigerants potential impact or lack of impact on the ozone was considered
  - Global Warming Potential
  - Toxicity
  - Flammability

26

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Views from industry
(Andy Pearson, Star Refrigeration Ltd)

- Important refrigerant considerations:
  - Cost of the refrigerant (or system)
  - Efficiency
  - Operating pressure
  - Cooling capacity
  - Ozone Depletion Potential
  - Global Warming Potential
    - The value is an estimate of whole life GWP*
    - It includes assumptions about production
  - Toxicity
  - Flammability

27

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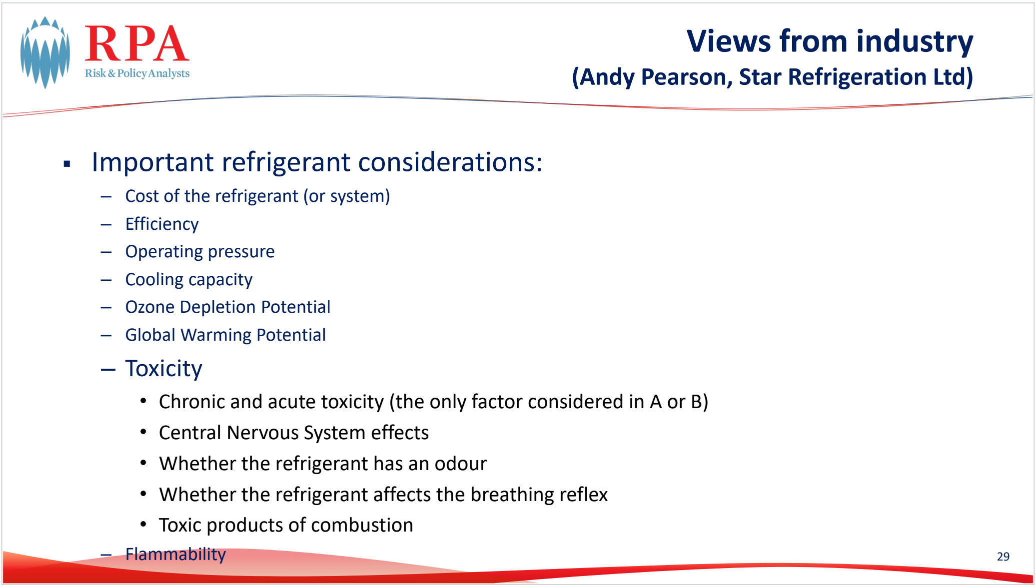
Global Warming Potential (GWP)

*Not discussed in detail here, but other GWP assessments have been made:

28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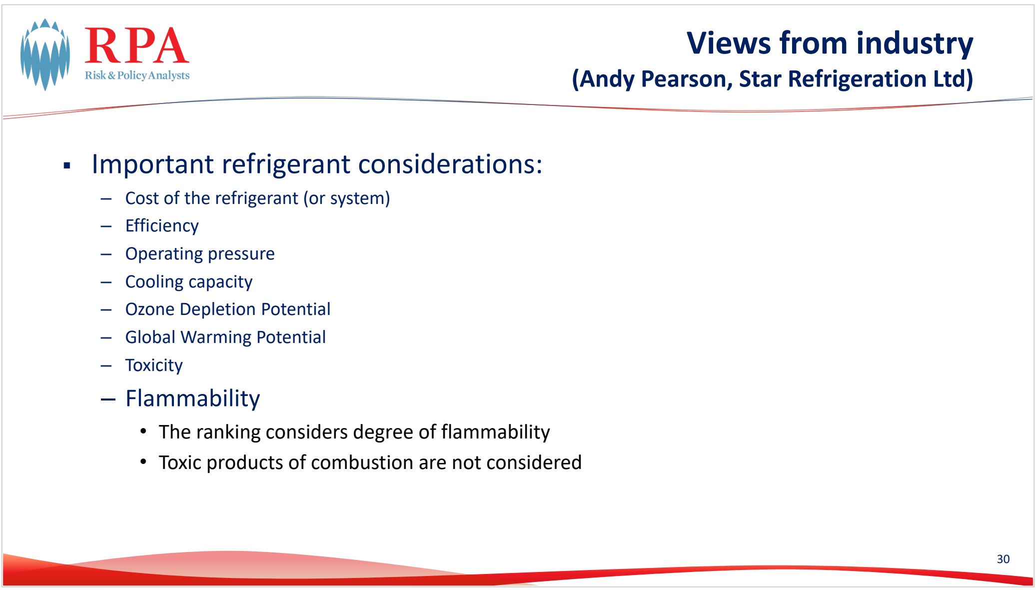
Views from industry
(Andy Pearson, Star Refrigeration Ltd)
Important refrigerant considerations:
– Cost of the refrigerant (or system)
– Efficiency
– Operating pressure
– Cooling capacity
– Ozone Depletion Potential
– Global Warming Potential
– Toxicity
• Chronic and acute toxicity (the only factor considered in A or B)
• Central Nervous System effects
• Whether the refrigerant has an odour
• Whether the refrigerant affects the breathing reflex
• Toxic products of combustion
– Flammability
29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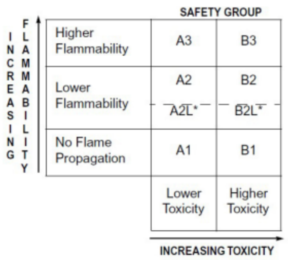
Views from industry
(Andy Pearson, Star Refrigeration Ltd)
Important refrigerant considerations:
– Cost of the refrigerant (or system)
– Efficiency
– Operating pressure
– Cooling capacity
– Ozone Depletion Potential
– Global Warming Potential
– Toxicity
– Flammability
• The ranking considers degree of flammability
• Toxic products of combustion are not considered
30

ASHRAE Standard 34

- Defines the flammability and toxicity of refrigerants
- The capital letter designates a toxicity class based on allowable exposure. The numeral denotes flammability
- Based in the International Fire Code, Uniform Fire Code, and (US) OSHA regulations
- Potential for toxicity and other classification divergence between EU and US

ASHRAE Standard 34 – Basis of Standard

- Safety Group Classifications



* A2L and B2L are lower flammability refrigerants with a maximum burning velocity of ≤3.9 in./s (10 cm/s).

https://www.ashrae.org/file%20library/technical%20resources/refrigeration/factsheet_ashrae_english_20200424.pdf

31

ASHRAE Standard 34

- Prospect of an A1, A2 or A3 to be considered more hazardous than the safety group

Refrigerants				
Number[a]	Chemical Name[a]	Safety Group[a]	Global Warming Potential (GWP100[b])	Normal Boiling Point, °F (°C)[a]
Unsaturated Organic Compounds				
1130(E)	trans-1,2-dichloroethene	B2	N/A[c]	117.9 (47.7)
1132a	1,1-difluoroethylene	A2	N/A[c]	–122.5 (–86.7)
1224yd(Z)	(Z)-1-chloro-2,3,3,3-tetrafluoropropene	A1	N/A[c]	58.1 (14.5)
1233zd(E)	trans-1-chloro-3,3,3-trifluoro-1-propene	A1	1	64.6 (18.1)
1234ze(E)	trans-1,3,3,3-tetrafluoro-1-propene	A2L	<1	–2.2 (–19.0)
13I1	trifluoroiodomethane	A1	N/A[c]	–7.4 (–21.9)
1336mzz(E)	trans-1,1,1,4,4,4-hexafluoro-2-butene	A1	N/A[c]	45.3 (7.4)
1336mzz(Z)	cis-1,1,1,4,4,4-hexaflouro-2-butene	A1	2	91.4 (33.4)

Refrigerant Blends							
Num.[a]	Composition (Mass %)[a]	Safety Group[a]	Global Warming Potential (GWP100[b])	Bubble Point, °F[a]	Dew Point, °F[a]	Bubble Point, °C[a]	Dew Point, °C[a]
Zeotropes							
407F	R-32/125/134a (30.0/30.0/40.0)	A1	1670	–51.0	–39.5	–46.1	–39.7
407G	R-32/125/134a (2.5/2.5/95.0)	A1	N/A[c]	–20.6	–17.0	–29.2	–27.2
407H	R-32/125/134a (32.5/15.0/52.5)	A1	N/A[c]	–48.5	–35.7	–44.7	–37.6
407I	R-32/125/134a (19.5/8.5/72.0)	A1	N/A[c]	–39.6	–27.4	–39.8	–33.0
417B	R-125/134a/600 (79.0/18.3/2.7)	A1	2740	–48.8	–42.7	–44.9	–41.5
417C	R-125/134a/600 (19.5/78.8/1.7)	A1	N/A[c]	–26.9	–20.6	–32.7	–29.2
419B	R-125/134a/E170 (48.5/48.0/3.5)	A2	N/A[c]	–35.3	–24.7	–37.4	–31.5

32

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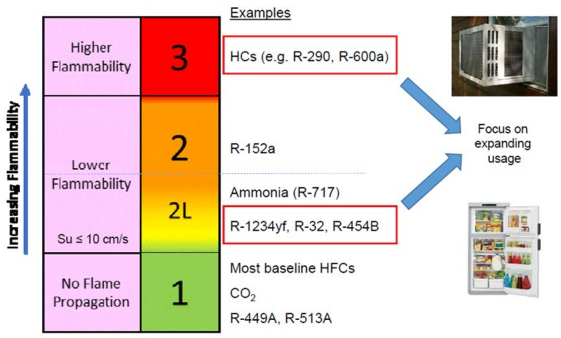
Views from industry
(Stephen Spletzer, Chemours)

Flammability Groups



33

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Views from industry
(Andy Pearson, Star Refrigeration Ltd)

- Scoring (higher is better):

	R-12	R-22	NH3	CO2	HC	R-134a	R-32	R-1234yf
Cost	6	5	8	9	6	4	3	1
Capacity	5	7	7	9	7	5	8	5
Flammability	9	7	5	10	3	7	5	5
ODP	1	3	10	10	10	10	10	10
Efficiency	7	6	7	6	7	5	7	4
GWP	1	3	9	9	9	3	5	7
Toxicity	7	7	3	5	7	7	9	8
Pressure	7	6	6	4	6	7	5	7

34

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Success stories

- There are clear trends to <u>lower GWP</u> substances in some markets (other alternatives may also exist):
  - Domestic refrigerators
    - HC-600a
  - Mobile air-conditioning
    - HFO-1234yf
  - Stand-alone retail refrigeration
    - HC-290
  - Air-conditioning and chillers
    - HFO-1234ze, HFO-1233zd, R-514A (HC and ammonia)
  - Large supermarket refrigeration
    - R-744 (CO_2)
  - Large industrial refrigeration
    - R-717 (ammonia); R-744

35

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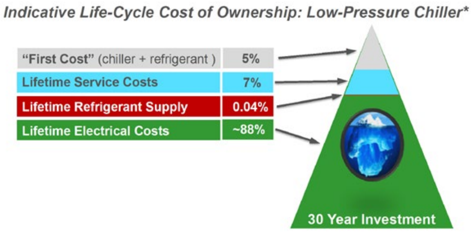
Success stories
(Mike Thompson, Ingersoll Rand)

Next Generation Refrigerant Options

	Current Refrigerant & GWP	Next Gen Refrigerant	GWP (AR4, EU F-gas Reg values)	Flamma-bility Class	% GWP Reduction	Prod Curr Available?
Design Compatible	R-410A (2088)	R-452B	698	2L	-67%	Y
	R-123 (77)	R-514A	< 2	1	-97%	Y
	R-134a (1430)	R-513A	631	1	-56%	Y
Minimal Redesign	R-410A (2088)	R-32	675	2L	-68%	Y
	R-134a (1430)	R-515A	393	1	-73%	N
	R-134a (1430)	R-1234ze	7	2L	-99.6%	Y
Major Redesign	R-123 (77)	R-1233zd	4	1	-95%	Y

Chiller Costs Calculated Across Long Lifetime



*Assuming modern coal-fired power plants with low transmission and distribution loss and refrigerant leakage rates of 0.5% per year; refrigerant cost for high-pressure chillers is a larger portion of life-cycle costs, but energy cost still dominates.

36

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Success stories

- Euro Tunnel, replacing R-22 with R-1233zd(E)
  - Energy savings of 33% have been achieved
  - Europe's largest cooling system, an energy reduction of 4.8GWh, relating to savings of approximately €500,000 in 2017.
  - Going forward, operators are confident that annual savings of around 40% can be sustained
  - 9% CO_2 reduction
  - But might R-1233zd have ODP that may lead to a ban?

37

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Success stories

- High GWP HFCs can all be avoided in new equipment and many sectors
- Moderate GWP options can contribute to a phase-down now
- Ultra-low GWP options in several important sectors are available now
- Article 5 (developing countries) could be encouraged to leap-frog high GWP refrigerants to ultra-low GWP
- The amount of options available may confuse end users, more options are being developed, however, the market may eventually be rationalised

38

END OF PART 1
QUESTIONS?

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Environmental and human health risk assessment – Methodology

- Consolidated and reviewed available data for TFA
  - Literature review
    - Accumulates in terminal sinks – i.e. oceans, playas, lakes
    - Only one aquatic study showed sensitivity (algae) – German Environment agency indicated how “the authors suspect a possible influence of trifluoroacetate on the citric acid cycle. Higher thresholds were found for other organisms such as duckweed and various higher land plants”
    - Limited human health effects – non-toxic, poorly absorbed, undergoes minimal metabolism and is rapidly cleared from the body
  - Other data sources
    - Substance Safety Data Sheets (SDS)
    - ECHA REACH registration dossier (manufactures & importers)
    - Quantified Structure-Activity Relationship (QSAR) data for selected data points – VEGA

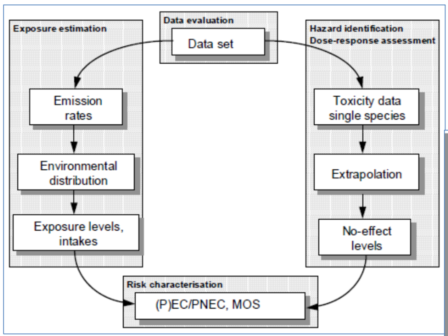
40

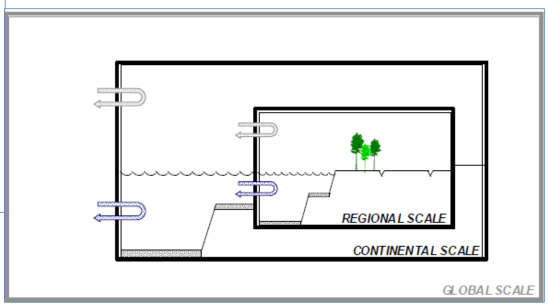
Risk assessment – EUSES

- What is ESUS?
  - EUSES is a model that predicts risk to environmental and human heath. For the environment Predicted Environmental Concentration (PECs) and Predicted No-Effect Concentration (PNECs) ratios are calculated. Margins of Safety (MOS) are generated for human health impacts
  - These are based on estimated emissions, releases, use patterns and known substance properties

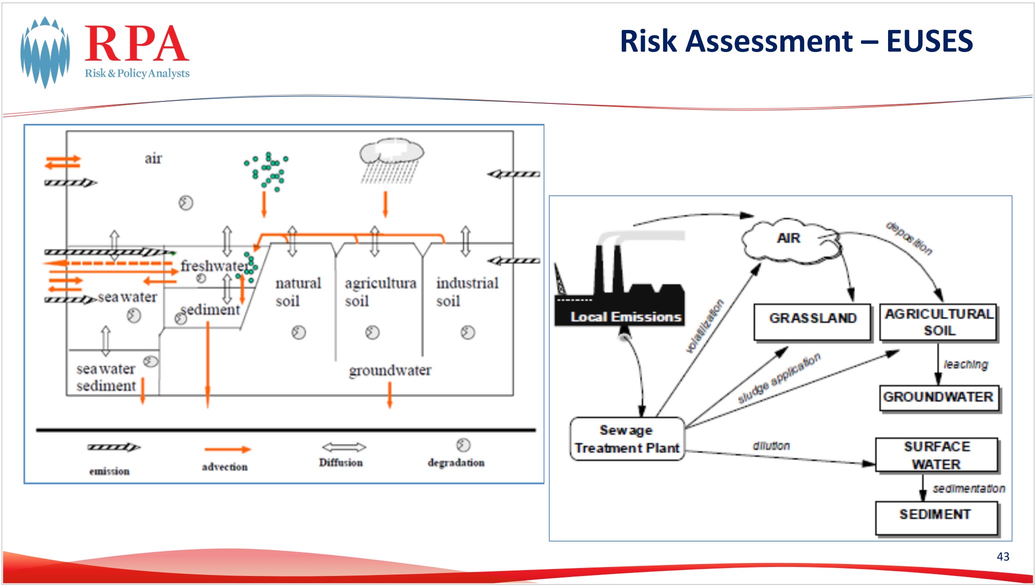
41

Risk assessment – EUSES





42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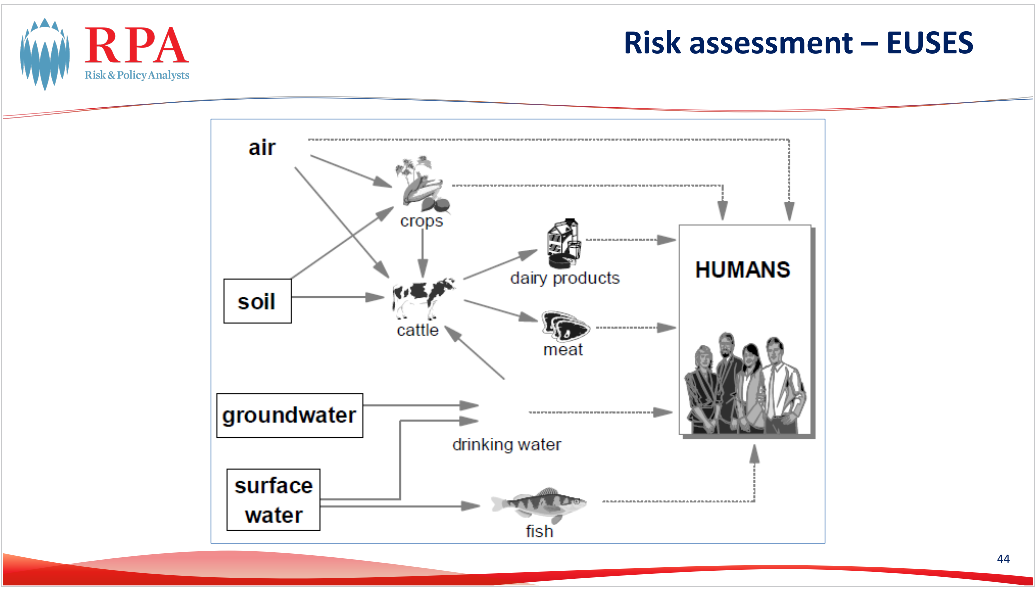
Risk Assessment – EUSES
air
freshwater
sea water
sediment
natural soil
agricultura soil
industrial soil
sea water sediment
groundwater
emission
advection
Diffusion
degradation
AIR
deposition
Local Emissions
volatilization
GRASSLAND
AGRICULTURAL SOIL
leaching
GROUNDWATER
sludge application
Sewage Treatment Plant
dilution
SURFACE WATER
sedimentation
SEDIMENT
43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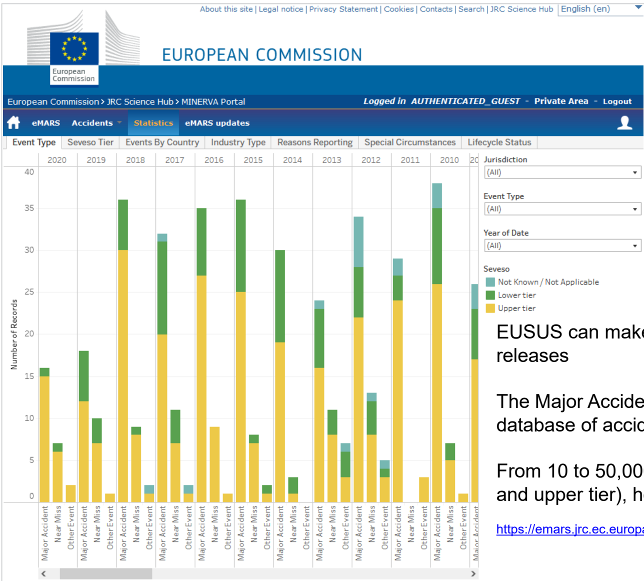
Risk assessment – EUSES
air
crops
soil
cattle
dairy products
meat
HUMANS
groundwater
drinking water
surface water
fish
44

Risk assessment – EUSES

- Challenges
  - EUSES is primarily designed for non-polar organic compounds
  - HFO-1234yf is the parent compound that is being produced and the one that will be emitted, whereas TFA is the breakdown substance that was modelled
  - There are some data gaps for TFA
  - Some questionable data - a large range in algae toxicity data, median algae data taken ("rough estimates", non-GLP studies, low quality studies, limit tests, and tests where only limited effects were identified)
- Adjustments
  - A very precautionary approach was taken
    - Assumed very high use patterns, high emissions to the environment and concentrations in the environment
    - Worst case data used – an expectation was for algae where we calculated average and median toxicity data

45



EUSUS can make some assumptions about accidental releases

The Major Accident Reporting System (eMARS) is an EU database of accidents based on the Seveso Directive

From 10 to 50,000 tonnes difference in flammability (lower and upper tier), how much will be stored on site?

https://emars.jrc.ec.europa.eu/en/emars/statistics/statistics

RPA — Environmental impacts – 2025 and 2100 Plateau

Usage/step	Fresh water	Marine	Fr. sed.	Mar. sed.	Soil	STP	Fish	Mar. fish	Mar. top	Worm
Non-Article 5 RCR for the environment, assessment for 2025 (average algae toxicity data)										
Chemical production	1.8 E-03	0.0218	0.018	0.0218	9.57	9.14 E-03	1.2 E-04	1.91 E-05	1.06E-05	0.0491
Personal/ domestic	0.0193	0.0231	0.0193	0.0231	0.0863	9.85 E-03	1.88 E-03	2.58 E-05	1.2 E-05	4.52 E-04
Light industrial use	0.0736	0.0774	0.0736	0.0774	0.0886	0.0386	1.07 E-04	1.78 E-05	1.03E-05	4.6 E-04
Non-Article 5 RCR for the environment, assessment for 2100 plateau (average algae toxicity data)										
Usage/step	Fresh water	Marine	Fr. sed.	Mar. sed.	Soil	STP	Fish	Mar. fish	Mar. top	Worm
Chemical production	1.7	17	17	24.3	9.01	9.01	0.0131	0.0131	2.62 E-03	0.123
Personal/ domestic	25.6	25.7	25.6	25.7	0.83	13.6	0.24	0.024	4.8 E-03	2.26 E-03
Light industrial use	54.2	54.2	54.2	1.66	28.7	28.7	0.0693	6.94 E-03	1.4 E-03	4.27 E-03

Fr. sed. = Fresh water sediment; Mar. Sed. = Marine sediment; STP = Sewage Treatment Plant; Mar. fish = Marine fish, Mar. top = Marine top predator

- A very precautionary approach was taken, risk characterisation ratios (RCR) >1 indicate a risk potential
- There does not appear to be a risk to species but TFA is expected to accumulate in various environments
- EUSES models chemical production, personal/domestic and light industrial use – alternatives to TFA exist in some of these sectors

47

RPA Risk & Policy Analysts — Environmental impacts – 2100 Phase out

- Risk Characterisation Ratio (RCR), PEC:PNEC, risk where the value is >1 (red)

Usage/step	Fresh water	Marine	Fr. sed.	Mar. sed.	Soil	STP	Fish	Mar. fish	Mar. top	Worm
Non-Article 5 RCR for the environment, assessment for 2100 phase-out MIT-5 (average algae toxicity data)										
Chemical production/ Storage facilities	0.0114	0.118	0.114	0.118	0.0951	0.0601	8.84 E-04	9.55 E-05	2.59 E-05	4.9 E-04
Personal/ domestic	2.6 E-03	6.39 E-03	2.6 E-03	6.39 E-03	0.848	9.85 E-04	3.13 E-05	1.02 E-05	8.82 E-06	4.46 E-04
Light industrial use	0.0574	0.0612	0.0574	0.0612	0.086	0.03	8.64 E-05	1.57 E-05	9.93 E-06	4.48 E-04

Fr. sed. = Fresh water sediment; Mar. Sed. = Marine sediment; STP = Sewage Treatment Plant; Mar. fish = Marine fish, Mar. top = Marine top predator

- HFO-1234yf (TFA) theoretically replaced (from 2050)
- Prior annual usage before phase out is not included in the model

48

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Human health impacts - 2025

- Margin Of Safety (MOS), risk where the value is <100 (red)

Non-Article 5 MOS for humans exposed to or via the environment, assessment for 2025 MIT-5								
Usage/step	Repdose Inh.	Repdose Total	Fert. Inh.	Fert. Total	Mater. Inh.	Mater. Total	Devel. Inh.	Devel. Total
Chemical production	7.55 E+10	6.32 E+03	7.55 E+10	6.32 E+03	1.13 E+10	947	1.13 E+10	947
Personal/ domestic	6.29 E+06	2.27 E+05	6.29 E+06	2.27 E+05	9.44 E+05	3.4 E+04	9.44 E+05	3.4 E+04
Light industrial use	4.6 E+06	1.81 E+05	4.6 E+06	1.81 E+05	6.89 E+05	2.72 E+04	6.89 E+05	2.72 E+04
Note: Carcinogenic threshold, non-threshold and CLR is not applicable Repdose = Repeat dose toxicity; Fert = Fertility toxicity; Mater. = Maternal toxicity; Devel. = Developmental toxicity; Inh. = Inhalation								

- No present risk to human health

49

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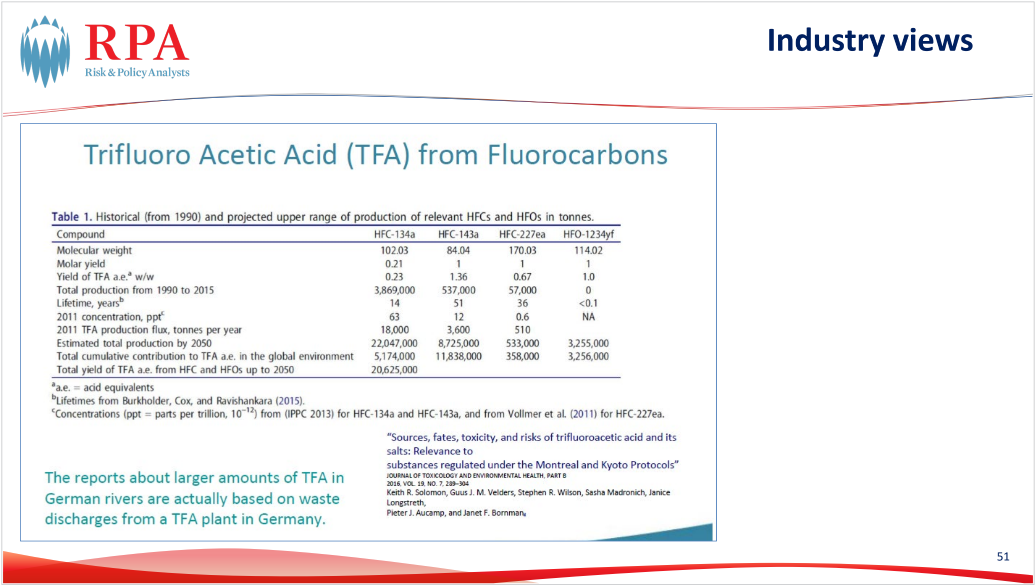
Human health impacts - 2100

- Margin Of Safety (MOS), risk where the value is <100 (red)

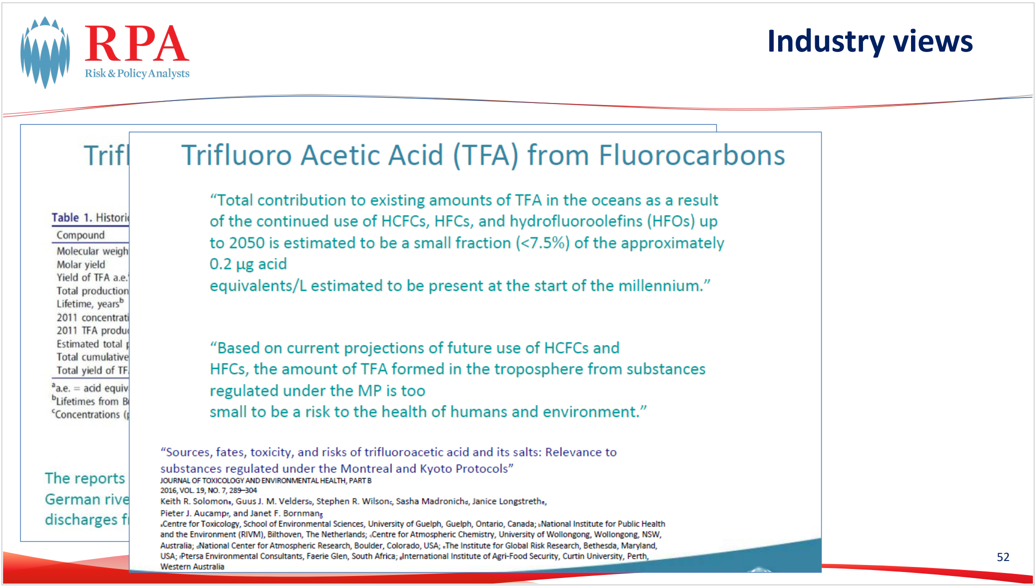
Non-Article 5 MOS for humans exposed to or via the environment, assessment for 2100 Plateau MIT-5								
Usage/step	Repdose Inh.	Repdose Total	Fert. Inh.	Fert. Total	Mater. Inh.	Mater. Total	Devel. Inh.	Devel. Total
Chemical production	6.26 E+10	2.43 E+03	6.26 E+10	2.43 E+03	9.4 E+09	364	9.4 E+09	364
Personal/domestic	3.15 E+06	2.8 E+03	3.15 E+06	2.8 E+03	4.72 E+05	420	4.72 E+05	420
Light industrial use	3.06 E+06	9.05 E+03	3.06 E+06	9.05 E+03	4.6 E+05	1.36 E+03	4.6 E+05	1.36 E+03
Note: Carcinogenic threshold, non-threshold and CLR is not applicable Repdose = Repeat dose toxicity; Fert = Fertility toxicity; Mater. = Maternal toxicity; Devel. = Developmental toxicity; Inh. = Inhalation								

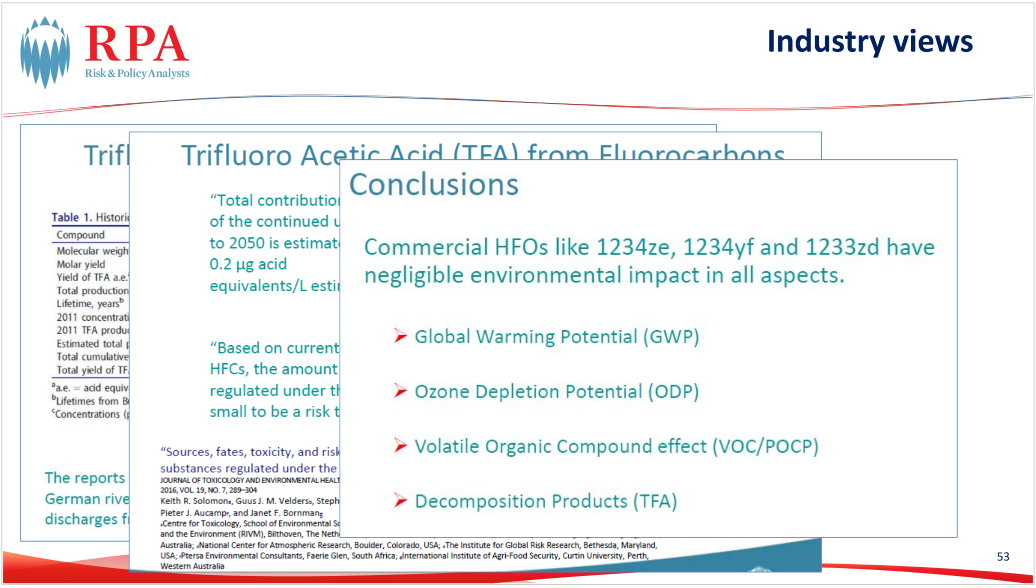
- In 2025 and 2100 plateau (where emissions are much higher) the MOS levels are far in excess of 100
- The highest risk occurs for Maternal and Developmental toxicity but the safety margins are still high
- The European Food Safety Authority also indicate that TFA is unlikely to pose a public health concern

50



Compound	HFC-134a	HFC-143a	HFC-227ea	HFO-1234yf
Molecular weight	102.03	84.04	170.03	114.02
Molar yield	0.21	1	1	1
Yield of TFA a.e.[a] w/w	0.23	1.36	0.67	1.0
Total production from 1990 to 2015	3,869,000	537,000	57,000	0
Lifetime, years[b]	14	51	36	<0.1
2011 concentration, ppt[c]	63	12	0.6	NA
2011 TFA production flux, tonnes per year	18,000	3,600	510	
Estimated total production by 2050	22,047,000	8,725,000	533,000	3,255,000
Total cumulative contribution to TFA a.e. in the global environment	5,174,000	11,838,000	358,000	3,256,000
Total yield of TFA a.e. from HFC and HFOs up to 2050	20,625,000			

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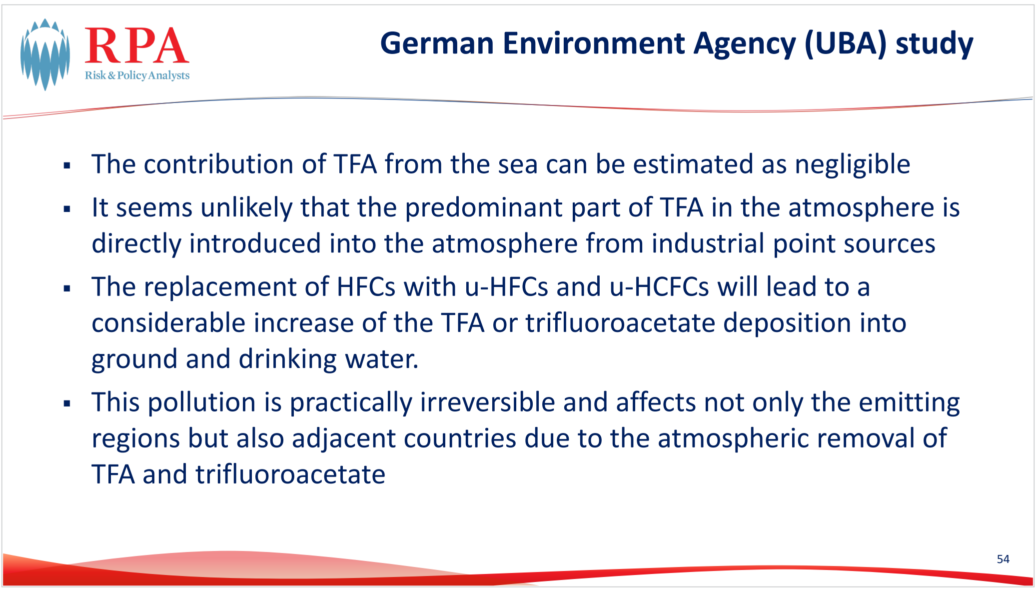
Industry views
Conclusions
Commercial HFOs like 1234ze, 1234yf and 1233zd have negligible environmental impact in all aspects.
Global Warming Potential (GWP)
Ozone Depletion Potential (ODP)
Volatile Organic Compound effect (VOC/POCP)
Decomposition Products (TFA)
53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German Environment Agency (UBA) study
The contribution of TFA from the sea can be estimated as negligible
It seems unlikely that the predominant part of TFA in the atmosphere is directly introduced into the atmosphere from industrial point sources
The replacement of HFCs with u-HFCs and u-HCFCs will lead to a considerable increase of the TFA or trifluoroacetate deposition into ground and drinking water.
This pollution is practically irreversible and affects not only the emitting regions but also adjacent countries due to the atmospheric removal of TFA and trifluoroacetate
54

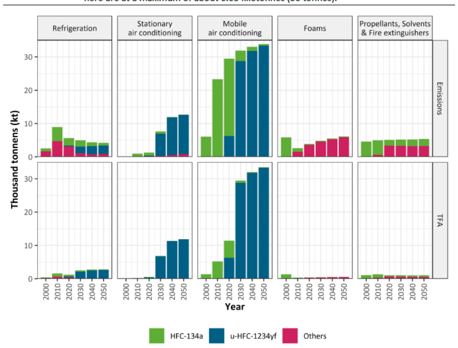
German Environment Agency (UBA) study

- In 2020, 15,000 tonnes will be emitted in the EU-28, which will rise until 2050 with around 50,000 tonnes/year being emitted
- The emissions of HFO-1234yf amounted to around 10 % of the total emissions in 2020, this will increase to around 60 % by 2030 and to approximately 70 % by 2050
- By 2030, the amount of TFA from the degradation of HFO-1234yf will increase significantly to approximately 37,000 tonnes
- TFA resulting from the degradation of HFC-134a will decrease to about 2,000 tonnes

55

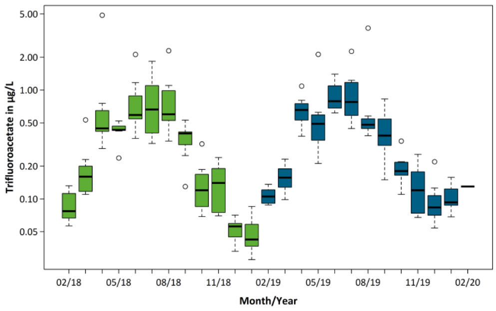
German Environment Agency (UBA) study

Figure S 4: European (EU-28) emissions of important HFCs, u-HFCs and u-HCFCs in refrigerants and blowing agents, and resulting trifluoroacetic acid (TFA) quantities in kilotonnes by sector for the years 2000 to 2050 in 10-year steps. All other projected TFA-forming substances are summarized as "Others". The sector "Others" is not shown, as the TFA quantities here are at a maximum of about 0.03 kilotonnes (30 tonnes).



Source: own research, Öko-Recherche

- UBA identified seasonal variation, HFO-1234yf is used in mobile air conditioning where use is typically higher in summer months:



Source: own research, Öko-Recherche and TZW Karlsruhe

56

German Environment Agency (UBA) study

"According to this, the absolute annual TFA deposition in tonnes in Germany and Europe (EU-27, Great Britain, Switzerland, and Turkey) will increase very sharply until 2030 and thereafter increase more slowly but continuously until 2050. In **Germany**, the average TFA deposition per area (kg/km^2) is well above the European average. Up to 2050, an increase in TFA deposition of approximately **4 kg/km^2** is to be expected. Compared to the mean deposition rates measured in this study, this would be an increase by a factor of 10. **For Europe, an average annual TFA deposition rate of 2.5 kg/km^2 can be expected by 2050."**

57

Danish findings

- TFA was found in 219 out of the 247 groundwater intakes analysed in 2020 (89%)
- The highest concentration measured in the mass screening is 2.4 µg/l
- The vast majority of findings have been made in concentrations below or equal to 1 µg/l, but in 212 cases they were above of 0.1 µg/l, corresponding to 86 per cent of the intakes studied
- The Environment Minister, Lea Wermelin:
  - "I am really concerned that a new chemical has been found in so many places in our groundwater. There must be security about drinking water. Therefore, I have immediately asked that we get a Danish health assessment and that we examine drinking water in all municipalities."

https://fvm.dk/nyheder/nyhed/nyhed/mange-forekomster-af-tfa-opdaget-i-grundvandet/?utm_campaign=mange-forekomster-af-tfa-opdaget-i-grundvandet&utm_medium=email&utm_source=fvm_nyhedsmail

58

German Environment Agency (UBA) views

- The increase of high persistence and mobility of TFA and trifluoroacetate leads to growing pollution of the groundwater and drinking water resources
- Since persistent substances remain in the environment for a long time and neither effective natural mechanisms nor acceptable technical processes for removing TFA from drinking water resources are known, potential harm to the environment and humans can only be prevented by minimizing the input of TFA and its precursors

59

German Environment Agency (UBA) views

- Even if the deposition of TFA and its precursors were to cease, an extremely long-lived substance such as TFA or trifluoroacetate would remain in the environment for at least several decades
- The results of the analyses and projections underline the need for action to avoid further deposition of TFA and TFA-forming substances into the environment. The use of halogenated refrigerants, foam blowing agents, aerosol propellants and further TFA precursors should therefore be avoided
- Alternatives with natural refrigerants should be preferred and promoted. Technologies such as electromobility can pave the way to halogen-free solutions in cars

60

European Commission: Chemicals Strategy for Sustainability - Towards a Toxic-Free Environment

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EUROPEAN COMMISSION

Brussels, 14.10.2020
COM(2020) 667 final

COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS

Chemicals Strategy for Sustainability
Towards a Toxic-Free Environment

{SWD(2020) 225 final} - {SWD(2020) 247 final} - {SWD(2020) 248 final} - {SWD(2020) 249 final} - {SWD(2020) 250 final} - {SWD(2020) 251 final}

https://ec.europa.eu/environment/pdf/chemicals/2020/10/Strategy.pdf

61

2.2.3. Towards zero chemical pollution in the environment

Hazardous chemicals and their complex interaction with other environmental stressors can have **long-term and large-scale environmental** impacts on the terrestrial and marine environment. They can contribute to the reduction of ecosystem resilience, leading to rapid declines in animal populations and, ultimately, to extinctions[56], as well as impacting human health and wellbeing, not least through the possible presence of contaminants in the food chain. It is estimated that 2.8 million potentially contaminated sites exist in the EU, mainly from waste disposal and treatment, posing a significant environmental hazard for terrestrial and aquatic ecosystems and affecting the productivity of soils[57]. The current regulatory and policy framework struggles to take this into account and needs to be strengthened.

CHEMICAL POLLUTION IN NATURAL ENVIRONMENT

The Commission will:

- propose new hazard classes and criteria in the CLP Regulation to fully address **environmental toxicity, persistency, mobility and bioaccumulation;**
- introduce **endocrine disruptors, persistent, mobile and toxic** and **very persistent and very mobile substances** as categories of substances of very high concern;
- ensure that the information made available to authorities on substances allows comprehensive **environmental risk assessments** by strengthening requirements across legislation;
- address the **impact** on the environment of the production and use of **pharmaceuticals** in the upcoming pharmaceuticals strategy for Europe[58];
- support research and development for **decontamination solutions** in terrestrial and aquatic environments;
- reinforce the regulation of **chemical contaminants in food** to ensure a high level of human health protection.

Per- and polyfluoroalkyl substances (PFAS) require special attention, considering the large number of cases of contamination of soil and water - including drinking water[59] - in the EU and globally[60], the number of people affected with a full spectrum of illnesses and the related societal and economic costs[61]. That is why the Commission proposes a comprehensive set of actions to **address the use of and contamination with PFAS**. Those aim to ensure, in particular, that the use of PFAS is phased out in the EU, unless it is proven essential for society.

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REACH Regulation:

2006R1907 — EN — 01.04.2016 — 028.001 — 208

▼M11

ANNEX XIII

CRITERIA FOR THE IDENTIFICATION OF PERSISTENT, BIOACCUMULATIVE AND TOXIC SUBSTANCES, AND VERY PERSISTENT AND VERY BIOACCUMULATIVE SUBSTANCES

This Annex lays down the criteria for the identification of persistent, bioaccumulative and toxic substances (PBT substances), and very persistent and very bioaccumulative substances (vPvB substances) as well as the information that must be considered for the purpose of assessing the P, B, and T properties of a substance.

For the identification of PBT substances and vPvB substances a weight-of-evidence determination using expert judgement shall be applied, by comparing all relevant and available information listed in Section 3.2 with the criteria set out in Section 1. This shall be applied in particular where the criteria set out in Section 1 cannot be applied directly to the available information.

A weight-of-evidence determination means that all available information bearing on the identification of a PBT or a vPvB substance is considered together, such as the results of monitoring and modelling, suitable in vitro tests, relevant animal data, information from the application of the category approach (grouping, read-across), (Q)SAR results, human experience such as occupational data and data from accident databases, epidemiological and clinical studies and well documented case reports and observations. The quality and consistency of the data shall be given appropriate weight. The available results regardless of their individual conclusions shall be assembled together in a single weight-of-evidence determination.

The information used for the purposes of assessment of the PBT/vPvB properties shall be based on data obtained under relevant conditions.

The identification shall also take account of the PBT/vPvB-properties of relevant constituents of a substance and relevant transformation and/or degradation products.

ECHA
EUROPEAN CHEMICALS AGENCY

GUIDANCE

Guidance on Information Requirements and Chemical Safety Assessment

Chapter R.11: PBT/vPvB assessment

Version 3.0

June 2017

Chapter R.11: PBT/vPvB assessment

24 **Version 3.0 – June 2017**

R.11.3.2.1 Scope of the PBT and vPvB assessment (relevant constituents, transformation/degradation products)

For the purpose of this Guidance it should be noted that the term "constituent" as mentioned in Annex XIII to the REACH Regulation refers to constituents and impurities of well-defined substances, constituents of UVCB substances, and additives to all substances.

The PBT/vPvB assessment must, according to Annex XIII to the REACH Regulation, take account of the PBT/vPvB properties of relevant constituents and relevant transformation and/or degradation products of organic substances (including organo-metals).

Generally, the PBT/vPvB assessment obligations as described in Sections R.11.3.1 and R.11.3.2 have to be applied for relevant constituents, impurities, additives and transformation/degradation products. The registrant cannot stop the PBT/vPvB assessment if there is not enough information available to take into account the PBT/vPvB properties of relevant constituents, impurities, additives and transformation/degradation products. This means that if there is not enough information available on the PBT/vPvB properties of relevant constituents, impurities, additives and transformation/degradation products to derive for the registrant's substance either conclusion (i) ("The substance does not fulfil the PBT and vPvB criteria") or conclusion (ii) ("The substance fulfils the PBT or vPvB criteria"), the registrant must generate the necessary further information on the PBT/vPvB properties of the relevant constituents, impurities, additives and transformation/degradation products until one of these two definitive conclusions can be achieved. The other option, as provided in Sections R.11.3.1 and R.11.3.3 is to treat the substance "*as if it is a PBT or vPvB*".

If the registrant deems as a result of the PBT/vPvB assessment an uncharacterized constituent, impurity, additive or transformation/degradation product relevant for the PBT/vPvB assessment, the registrant must characterize its substance identity as required in the *Guidance for identification and naming of substances under REACH and CLP*.

The interpretation of the term "relevant" constituent, impurity, additive, transformation/degradation product, is described in Section R.11.4.1. It is recommended that the registrant follows this interpretation in the PBT/vPvB assessment, in defining which constituents, impurities, additives, transformation or degradation products are relevant.

The registrant must show in the PBT/vPvB assessment that he has taken into account the relevant constituents, impurities and additives. This is normally possible only if he includes in the PBT/vPvB assessment appropriate justifications for all constituents, impurities and additives or for all fractions/blocks of the substance composition on why these are considered to be relevant or judged to be not relevant for the PBT/vPvB assessment, regardless of whether the substance identity of these could be ultimately determined or not[5]. The registrant may derive such reasoning quantitatively or qualitatively, by using the PBT/vPvB assessment principles as described in Section R.11.4. This also applies to the transformation/degradation products. It should be noted that also Section 9.2.3 of Annex IX to the REACH Regulation requires identification of degradation products.

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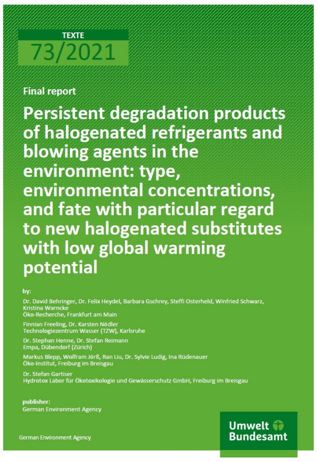
TEXTE 73/2021

Final report

Persistent degradation products of halogenated refrigerants and blowing agents in the environment: type, environmental concentrations, and fate with particular regard to new halogenated substitutes with low global warming potential

by:

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publisher:
German Environment Agency

German Environment Agency

Umwelt Bundesamt

https://www.umweltbundesamt.de/publikationen/persistent-degradation-products-of-halogenated

Atmospheric Degradation

Once these gases have been released into the atmosphere, atmospheric degradation starts with an initial reaction, primarily with OH radicals. Halogenated carbonyl compounds are formed as intermediate products. The type of intermediate product determines the further degradation pathway in the atmosphere. For HFCs, u-HFCs and u-HCFCs, most of the halogenated carbonyl compounds formed are further broken down to hydrogen fluoride (HF) and carbon dioxide (CO_2), except for the two compounds trifluoroacetyl fluoride (TFF, CF_3CFO) and trifluoroacetaldehyde (CF_3CHO). With water, TFF reacts completely to the highly persistent and highly mobile trifluoroacetic acid (TFA, CF_3COOH). For trifluoroacetaldehyde, a TFA formation rate of up to 10 % can be assumed. Now and in the future, large quantities of two substances that strongly form TFA will be used, namely HFC-134a, of which 7-20 % is degraded to TFA on a molar basis and u-HFC-1234yf, which completely degrades to TFA (Figure S 1). Additionally, there are further halogenated gases that form TFA during atmospheric degradation (see Table 14 in Chapter 2.7.4 and Table 15 in Chapter 2.8).

RPA Risk & Policy Analysts

RPA Risk & Policy Analysts

Regulatory Management Option Analysis (RMOA)

- Industry can conduct a RMOA
- This investigates all of the regulatory options, including the possible restriction but continued use of substances
- European Union Member States may also consider similar measures
- Good seals, leek detection, leek reduction and recycling operations
- Potential for regrettable substitutions - when one chemical is banned, only to be replaced with another chemical just as harmful, or potentially worse

66

Leak reduction

- At present there is limit guidance on leak detection systems or capabilities in regulations or standards
- Engineering solutions may help to reduce leaks
- HFO leak detection an be identified by at least two primary sensor technologies with different minimum detectable levels
- Solutions suitable for refrigerant safety monitoring & compliance
- Typically semiconductor (MOS) sensors
  - Solutions suitable for economic benefits, reducing leak rates & reducing environmental impact
- Typically infra red sensors
  - Leak detection system effectiveness requires integration to systems to alert personnel & initiate repair

67

Leak reduction

Semiconductor sensors

- Cost effective solution, versatile, broad-range sensors and have fast response times
- But typically they are non-selective - respond to any reducing gas, affected by water vapour, humidity, temperature, low oxygen, prone to false alarms, detection typically >100 ppm
- Suitable for gross leak detection of gas levels below refrigerant safety thresholds

68

Leak reduction

Infrared sensors

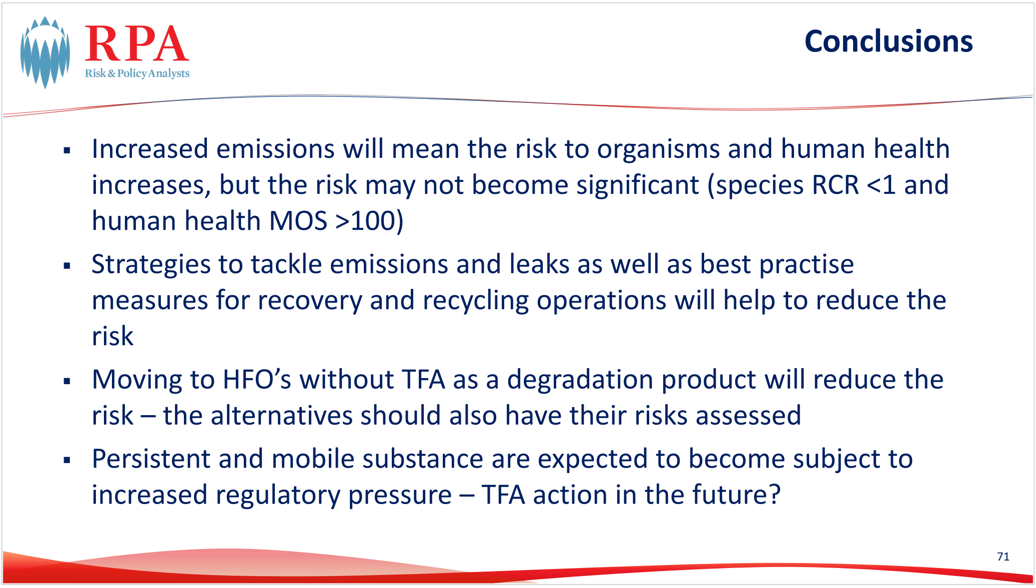
- They have fast response times and several systems available with detection limits around 20-25 ppm, detection of 1 ppm widely proven
- But cost & sensor size can make it impractical to locate multiple sensors at each required monitoring location, also the are typically less versatile as they do not response to gases with absorption at different wavelengths
- Suitable for delivering economic benefits & environmental protection in addition to detecting below levels required for safety

69

Conclusions

- HFO-1234yf is one the most widely used HFO refrigerants on the market, it is also used in a selection of HFO blends, the market and emissions of HFO-1234yf are expected to grow
- TFA is the main degradation product of HFO-1234yf and HFO-1216
- TFA is not expected to be bioaccumulative and has not been shown to exhibit toxicological properties of concern
- However, TFA is very persistent and concentrations will only be expected to increase in the environment and drinking water – ultimate breakdown products?

70


RPA
Risk & Policy Analysts
Conclusions
Increased emissions will mean the risk to organisms and human health increases, but the risk may not become significant (species RCR <1 and human health MOS >100)
Strategies to tackle emissions and leaks as well as best practise measures for recovery and recycling operations will help to reduce the risk
Moving to HFO's without TFA as a degradation product will reduce the risk – the alternatives should also have their risks assessed
Persistent and mobile substance are expected to become subject to increased regulatory pressure – TFA action in the future?
71


RPA
Risk & Policy Analysts
Thank you!
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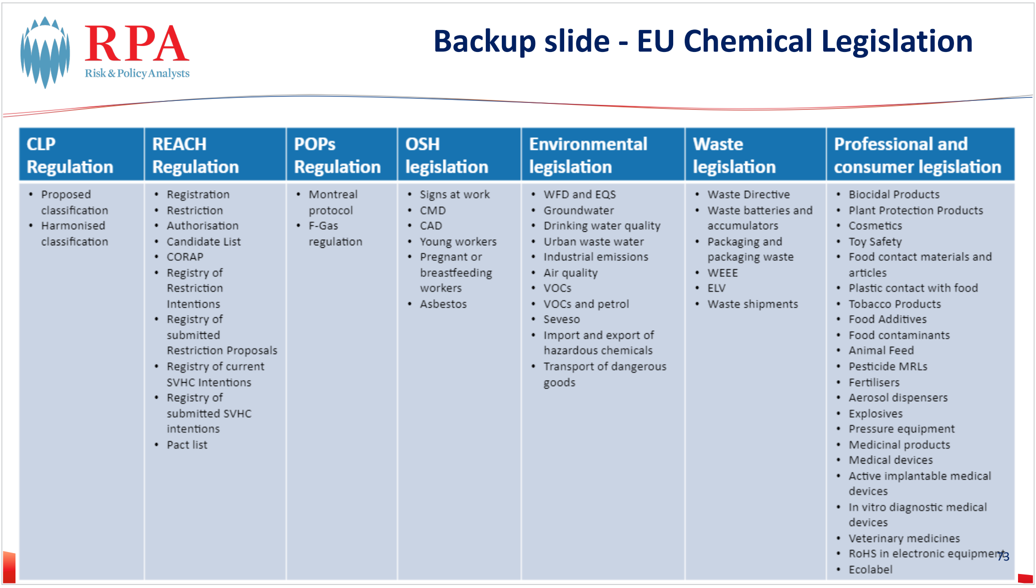
Suite C, 2nd floor, The Atrium,
St Georges Street,
Norwich, Norfolk,
NR3 1AB, UK
www.rpaltd.co.uk


RPA
Risk & Policy Analysts
Backup slide - EU Chemical Legislation
CLP Regulation
• Proposed classification
• Harmonised classification
REACH Regulation
• Registration
• Restriction
• Authorisation
• Candidate List
• CORAP
• Registry of Restriction Intentions
• Registry of submitted Restriction Proposals
• Registry of current SVHC Intentions
• Registry of submitted SVHC intentions
• Pact list
POPs Regulation
• Montreal protocol
• F-Gas regulation
OSH legislation
• Signs at work
• CMD
• CAD
• Young workers
• Pregnant or breastfeeding workers
• Asbestos
Environmental legislation
• WFD and EQS
• Groundwater
• Drinking water quality
• Urban waste water
• Industrial emissions
• Air quality
• VOCs
• VOCs and petrol
• Seveso
• Import and export of hazardous chemicals
• Transport of dangerous goods
Waste legislation
• Waste Directive
• Waste batteries and accumulators
• Packaging and packaging waste
• WEEE
• ELV
• Waste shipments
Professional and consumer legislation
• Biocidal Products
• Plant Protection Products
• Cosmetics
• Toy Safety
• Food contact materials and articles
• Plastic contact with food
• Tobacco Products
• Food Additives
• Food contaminants
• Animal Feed
• Pesticide MRLs
• Fertilisers
• Aerosol dispensers
• Explosives
• Pressure equipment
• Medicinal products
• Medical devices
• Active implantable medical devices
• In vitro diagnostic medical devices
• Veterinary medicines
• RoHS in electronic equipment
• Ecolabel
73

Agenda

A — What is a Intermodal Container refrigeration system (aka Reefer) and how does it operate?

B — What refrigerant solutions are considered and how do they perform?

C — What impact do refrigerants have on the environment?

Refrigerant options in Intermodal Container refrigeration systems

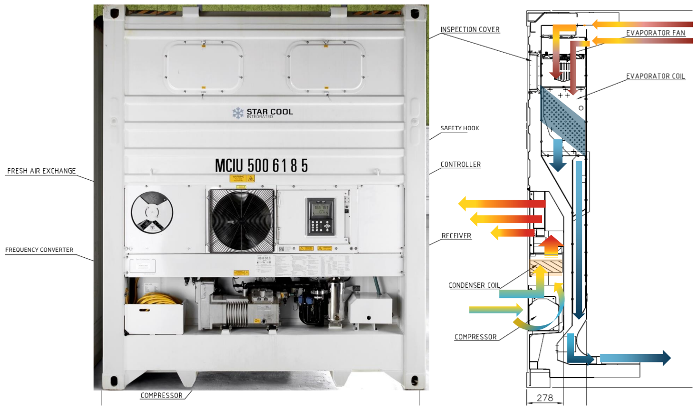
MAERSK CONTAINER INDUSTRY

What is a Intermodal Container refrigeration system (aka Reefer) and how does it operate?

3 Refrigerant options in Intermodal Container refrigeration systems

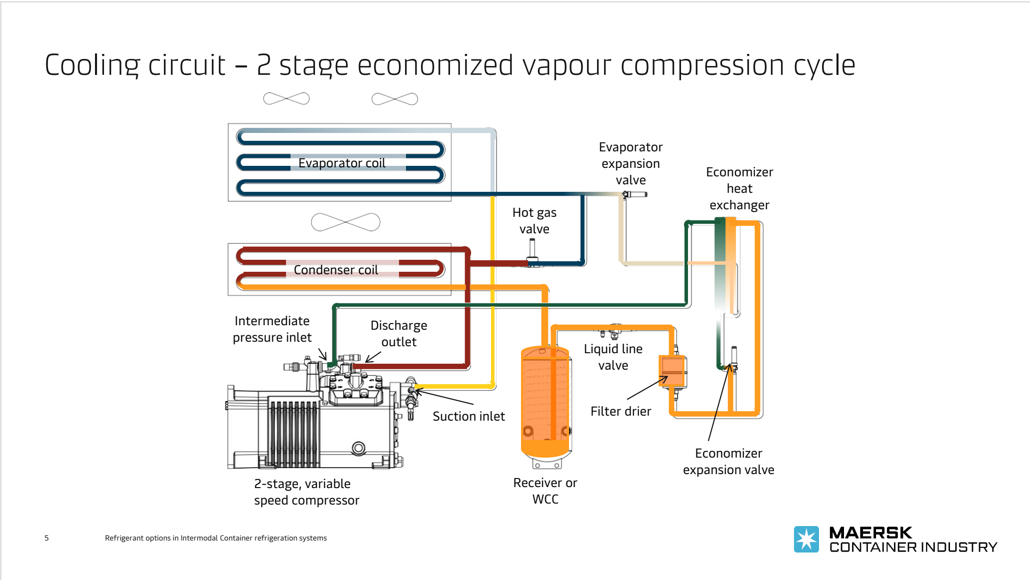
MAERSK CONTAINER INDUSTRY

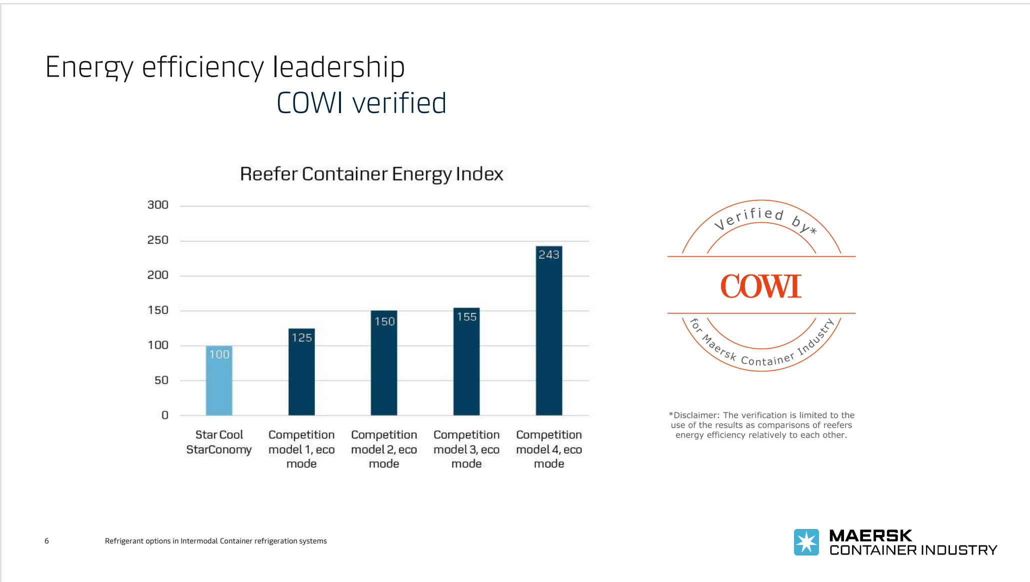
Component layout & Unit airflow

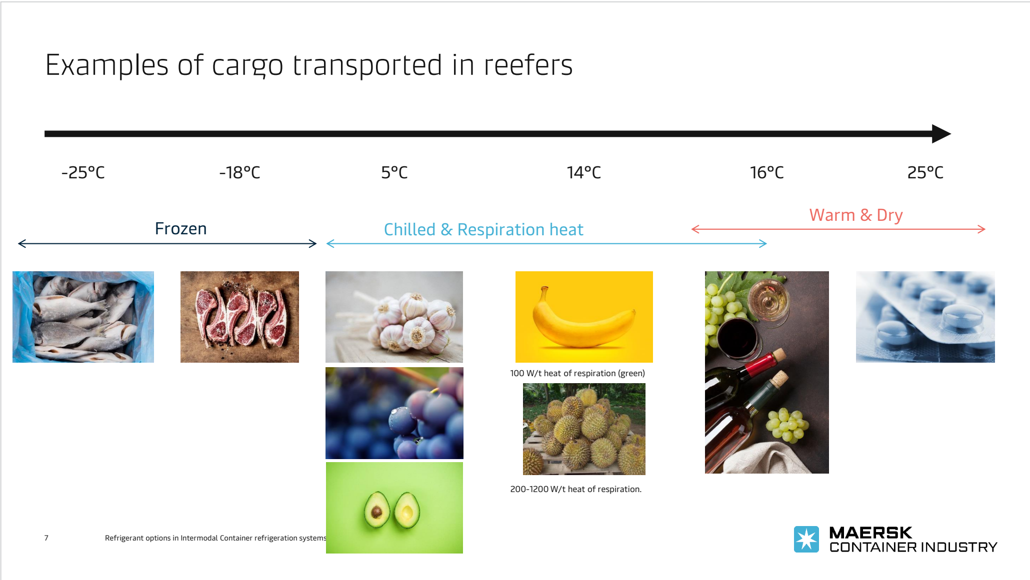


4 Refrigerant options in Intermodal Container refrigeration systems

MAERSK CONTAINER INDUSTRY


Cooling circuit – 2 stage economized vapour compression cycle
Evaporator coil
Evaporator expansion valve
Economizer heat exchanger
Hot gas valve
Condenser coil
Intermediate pressure inlet
Discharge outlet
Liquid line valve
Filter drier
Suction inlet
Economizer expansion valve
2-stage, variable speed compressor
Receiver or WCC
5
Refrigerant options in Intermodal Container refrigeration systems
MAERSK CONTAINER INDUSTRY


Energy efficiency leadership
COWI verified
Reefer Container Energy Index
300
250
200
150
100
50
0
100
125
150
155
243
Star Cool StarConomy
Competition model 1, eco mode
Competition model 2, eco mode
Competition model 3, eco mode
Competition model 4, eco mode
Verified by*
COWI
for Maersk Container Industry
*Disclaimer: The verification is limited to the use of the results as comparisons of reefers energy efficiency relatively to each other.
6
Refrigerant options in Intermodal Container refrigeration systems
MAERSK CONTAINER INDUSTRY


Examples of cargo transported in reefers
-25°C
-18°C
5°C
14°C
16°C
25°C
Frozen
Chilled & Respiration heat
Warm & Dry
100 W/t heat of respiration (green)
200-1200 W/t heat of respiration.
7
Refrigerant options in Intermodal Container refrigeration systems
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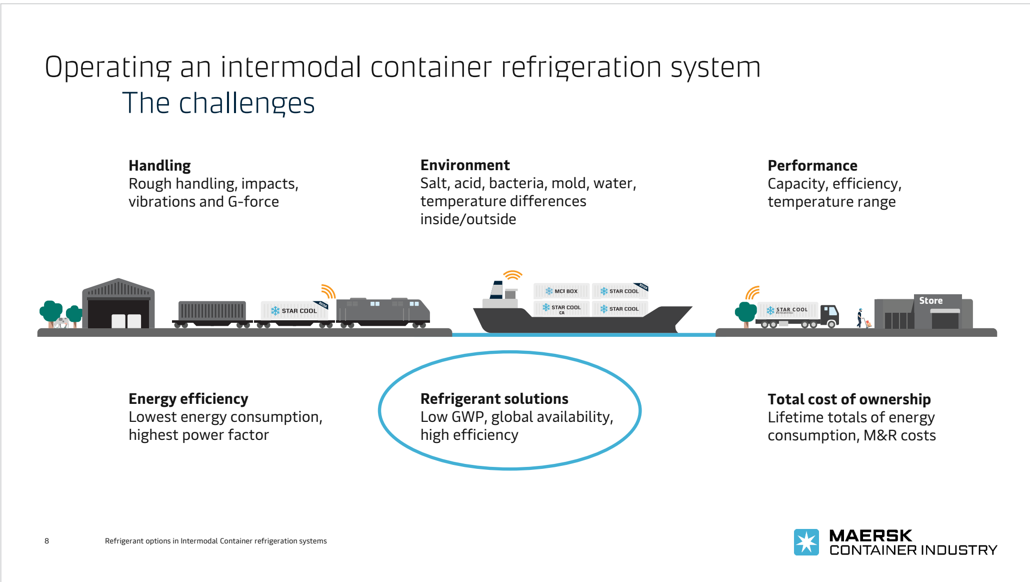
CONTAINER INDUSTRY


Operating an intermodal container refrigeration system
The challenges
Handling
Rough handling, impacts, vibrations and G-force
Environment
Salt, acid, bacteria, mold, water, temperature differences inside/outside
Performance
Capacity, efficiency, temperature range
Store
Energy efficiency
Lowest energy consumption, highest power factor
Refrigerant solutions
Low GWP, global availability, high efficiency
Total cost of ownership
Lifetime totals of energy consumption, M&R costs
8
Refrigerant options in Intermodal Container refrigeration systems
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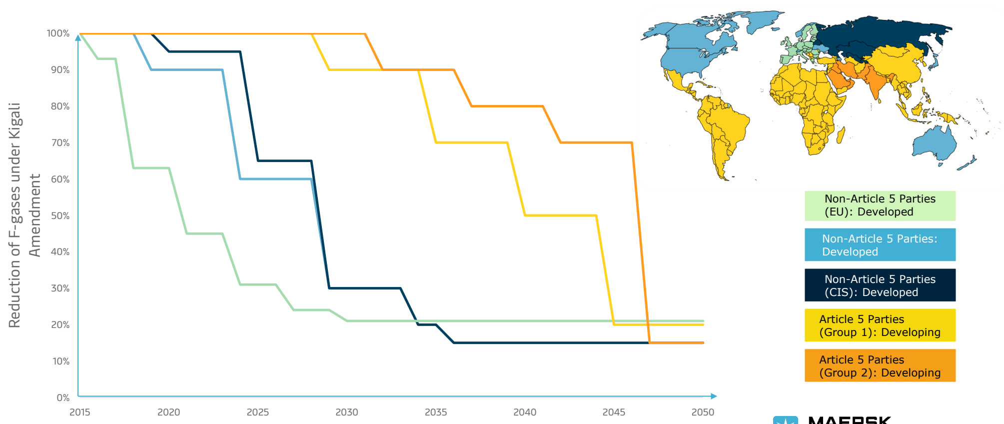
Refrigerants in Reefers are impacted by global policies



9 Refrigerant options in Intermodal Container refrigeration systems

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What refrigerant solutions are considered and how do they perform?

10 Refrigerant options in Intermodal Container refrigeration systems

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Refrigerants

- Phased-out solutions
  - R12
  - R22
- Already in use today
  - R134a
  - R513A
  - R404A
  - R452A
- Discussed future options
  - R290
  - R1270
  - R1234yf
  - R744*

*Study by König, Enkemann in 2013 showed that "the COP of a R744 cycle is significantly lower (70%)". Even for optimized cases, the performance is of "the optimized CO_2 cycle show still -30%, in the case of using an theoretical expansion machine the COP of CO_2 is -15% (average) vs. the other refrigerants."

11 Refrigerant options in Intermodal Container refrigeration systems

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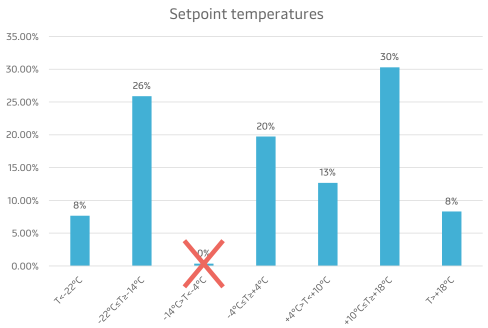
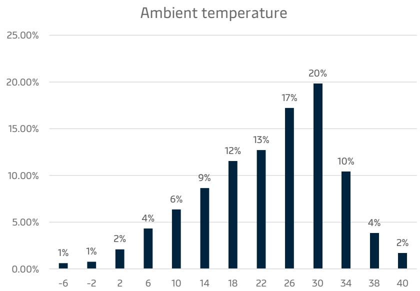
Temperature profile





12 Refrigerant options in Intermodal Container refrigeration systems

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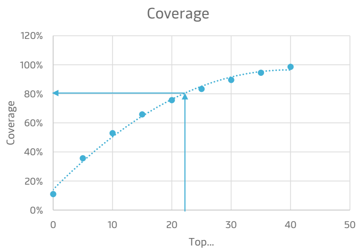
Operational envelope of reefer

Ambient Temperature		Setpoint temperature						
T [°C]		T<-22°C	-22°C≤T≥-14°C	-14°C>T<-4°C	-4°C≤T≥+4°C	+4°C>T<+10°C	+10°C≤T≥+18°C	T>+18°C
	Occurance [%]	8%	26%	0%	20%	13%	30%	8%
-6	0.61%	0%	0%	0%	0%	0%	0%	0%
-2	0.76%	0%	0%	0%	0%	0%	0%	0%
2	2.09%	0%	1%	0%	0%	0%	1%	0%
6	4.32%	0%	1%	0%	1%	1%	1%	0%
10	6.36%	0%	2%	0%	1%	1%	2%	1%
14	8.65%	1%	2%	0%	2%	1%	3%	1%
18	11.55%	1%	3%	0%	2%	1%	3%	1%
22	12.71%	1%	3%	0%	3%	2%	4%	1%
26	17.22%	1%	4%	0%	3%	2%	5%	1%
30	19.82%	2%	5%	0%	4%	3%	6%	2%
34	10.40%	1%	3%	0%	2%	1%	3%	1%
38	3.82%	0%	1%	0%	1%	0%	1%	0%
40	1.70%	0%	0%	0%	0%	0%	1%	0%

Heating Cooling



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Simulation

- Top 22 conditions are modelled – in part load (90%) and pull-down (10%). Heating disregarded as mainly done by evaporator fans and/or elect. heaters.
- Part-load capacity determined by

$$\dot{Q}_{evap} = UA_{box} \cdot (T_{amb} - T_{box}) + \dot{Q}_{fans} + \dot{Q}_{cargo}$$

- UA_{box} is equal to the maximum heat leakage from ISO 1496-2:2018, multiplied by an aging factor of 1.2 (40' HC Reefer considered only).
- Ideal, adiabatic compressor. Volume flow rate determined from +50°C/-30°C condition.

$$\eta_{is,1st} = \eta_{is,2nd} = \eta_{vol,1st} = \eta_{vol,2nd} = 1 \text{ and } \frac{\dot{V}_{1st}}{\dot{V}_{2nd}} = 2$$

- Evaporation pressure

$$p_0 = p_{sat}(0.8782 \cdot T_0 - 12.628) \text{ (pull-down)}, \ p_0 = p_{sat}(1.0203 \cdot T_0 - 5.3844) \text{ (part-load)}$$

- Condensing pressure (pull-down)

$$p_c = p_{sat}(max(0.4167 \cdot T_0 + 60.11, T_{amb} + 12K))$$

- Intermediate pressure (pull-down)

$$p_{int} = p_{sat}(0.4 \cdot T_c + 0.6 \cdot T_0 + 3) \text{ [A. Rasi, 1955]}$$

- Economizer mass flow rate found by solving mass balance around compressor

$$\dot{m}_{1st} + \dot{m}_{eco} = \dot{m}_{2nd}$$

- Superheat at Evaporator and Economizer is set to 5 K in all conditions and refrigerants.
- In part-load: iterating compressor speed, condensing pressure, economizer pressure to solve mass balance, capacity requirement and condenser limitations.

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Results I

Number of trips per container and year: 6
Number of days per trip: 21
Number of hours in operation: 2448

Differences in capacity between refrigerants are handled by linear adjustment of power

Refrigerant	Capacity [kW]	Power [kW]	COP [-/-]
R134a	3.14	2.08	1.51
R513A	3.14	2.18	1.44
R1234yf	3.05	2.15	1.42
R290	2.87	2.15	1.34
R1270	2.84	2.14	1.32
R404A	2.90	2.19	1.34
R452A	2.91	2.16	1.33
R12	2.99	2.18	1.37
R22	2.95	2.21	1.33

Refrigerant	Energy [kWh/y]	rel. to R134a
R134a	6300	100%
R513A	6593	105%
R1234yf	6696	106%
R290	7094	113%
R1270	7152	114%
R404A	7189	114%
R452A	7064	112%
R12	6911	110%
R22	7115	113%

15 Refrigerant options in Intermodal Container refrigeration systems

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What impact do refrigerants have on the environment?

16 Refrigerant options in Intermodal Container refrigeration systems

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Total Environmental Warming Impact (TEWI)

TEWI takes the direct and indirect refrigerant emissions into account.

$$TEWI = E_{operation} \cdot f_{fuel} + f_{leak} \cdot GWP_{100}$$

Leak rate f_{leak} is estimated at 15% annually [4th IMO GHG study, 2020].

Fuel factor f_{Fuel} is estimated to be 0.75 kg CO_2 per kWh, including vessel and land-based operation.

Refrigerant	Energy [kWh/y]	Fuel factor [kg CO_2 per kWh]	GWP-100 (6th AR IPCC)	Leak rate [%]	Avg. Charge in reefers [kg]	Indirect Emissions [kg CO_2]	Direct Emissions [kg CO_2]	TEWI	rel. TEWI
R134a	18900		1530		4.8	14175	1102	15276	100%
R513A	19778		673		4.5	14833	454	15287	100%
R1234yf	20087		0.5		4.5	15065	0	15065	99%
R290	21283		0.02		2.5	15962	0	15962	104%
R1270	21457	0.75	0.02	15%	2.5	16093	0	16093	105%
R404A	21566		4728		5.2	16175	3688	19863	130%
R452A	21192		2292		5.2	15894	1788	17682	116%
R12	20734		11200		4.5	15551	7560	23111	151%
R22	21345		1960		4.5	16009	1323	17332	113%

17 Refrigerant options in Intermodal Container refrigeration systems

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Total Environmental Warming Impact (TEWI)

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R134a	6300		1530		4.8	4725	1102	5827	100%
R513A	6593		673		4.5	4944	454	5399	93%
R1234yf	6696		0.5		4.5	5022	0	5022	86%
R290	7094		0.02		2.5	5321	0	5321	91%
R1270	7152	0.75	0.02	15%	2.5	5364	0	5364	92%
R404A	7189		4728		5.2	5392	3688	9079	156%
R452A	7064		2292		5.2	5298	1788	7086	122%
R12	6911		11200		4.5	5184	7560	12744	219%
R22	7115		1960		4.5	5336	1323	6659	114%

18 Refrigerant options in Intermodal Container refrigeration systems

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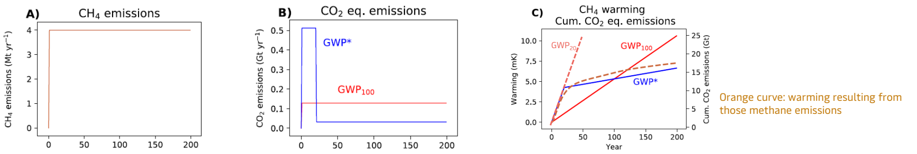
Emissions based on GWP*

A more suitable metric to assess environmental impact

- GWP* was proposed by Allen et. al in 2016 as it gives a better "environmental integrity" than integrative measures such as GWP-100.
- GWP* relates changes in emission to equivalent cumulative emissions of CO_2 and thereby gives a better correlation to the temperature change as effect of the GHG emission.
- This makes it a suitable tool to align policies to the targets of the Paris Agreement
- GWP-100 performs poorly to capture temperature response for short-living climate pollutants (e.g. Methane, 11.8 y). [Allen et al. 2016]
- GWP-20 "would just simply scale up and down (…) the emissions (…), making no difference to their poor temporal correspondence with (…) temperature response.



Figures from John Lynch et al 2020 Environ. Res. Lett. 15 044023

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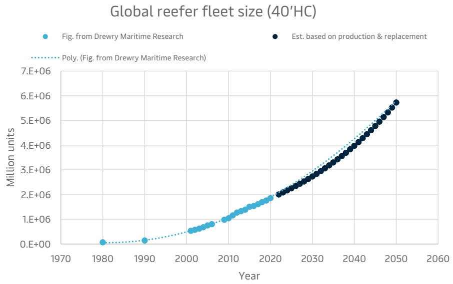
GWP* Emissions of global reefer fleet

- Emission profile of reefers from Simulation
- Time horizon: up to 2050 (= Paris target)
- 20 year lifetime of reefers
- Distribution of refrigerants in fleet:
  - 2006: 80% R134a, 20% R404A (4th IMO report)
  - 2020: 87% R134a, 13% R404A (own estimation)

$$E(t) = 4.53 \cdot [m(t) \cdot GWP_{100}] - 4.25 \cdot [m(t-20) \cdot GWP_{100}]$$



- Above equation is derived from Smith et al (2021) and quoted in 6th IPCC report (2021).
- Smith et al. discuss that a shorter period than 20 years could better represent shorter-living climate pollutants, but propose a consistent valve due for all short-living substances due to simplicity.

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Scenarios

- Baseline (Business as usual): Emissions are calculated based on R134a and R404A as projected in the fleet
- Scenario #1 (Drop-in & Retrofit): R513A replaces R134a and R452A replaces R404A in Year 0
- Scenario #2 (Drop-in & Retrofit): R513A replaces R134a and R452A replaces R404A in Year 0 for old fleet, new builds with R1234yf
- Scenario #3 (New Platform): R290 in new builds, no retrofit program
- Scenario #4 (New Platform): R290 in new builds, R513A for existing R134a units

21 Refrigerant options in Intermodal Container refrigeration systems

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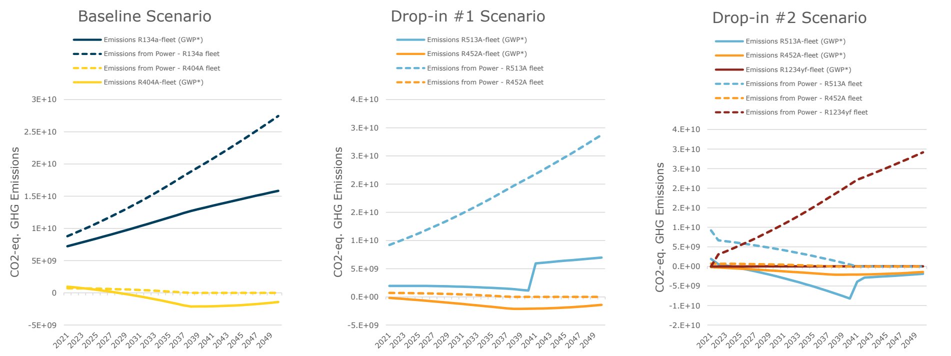
Results II



22 Refrigerant options in Intermodal Container refrigeration systems

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Results IV

Scenarios		ALL EMISSIONS	ALL EMISSIONS, rel. to BASELINE
Baseline	Emissions are calculated based on R134a and R404A projected fleet with GWP*	8.53E+11	100%
#1	R134a is replaced with R513A and R404A with R452A in y0 with GWP*	6.12E+11	72%
#2	R134a is replaced with R513A for existing, R1234yf for new builds and R404A with R452A in y0 with GWP*	4.34E+11	51%
#3	R290 for new builds, NO RETROFIT PROGRAM	5.05E+11	59%
#4	R290 for new builds, R513A for existing R134a units.	4.93E+11	58%

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Concluding remarks

- Energy consumption is the dominant factor for reefers and has greatest environmental impact.
- Refrigerant contributions become more dominant with improvements to energy consumption are made (SW, HW).
- For alternative refrigerant solutions, dedicated HW may be selected, such as adjusted Condenser and Evaporator, to improve performance. This will in most cases however require an increased Bill of Material, investments for spare parts and increased CO_2 footprint.
- Drop-in refrigerants such as R513A enable the industry to lower CO_2 footprint of existing units but are themselves not the final solution.
- Flammable refrigerants are the way forward in the reefer application! ISO 20854-2019 gives guidance on design and operation.
- For now R1234yf appears to be the ideal candidate, due to the close match in performance to R134a and to R134a design.
- Other environmental issues (TFA, HF) may be a showstopper for R1234yf, but scientific evidence is needed. Sola dosis facit venenum…

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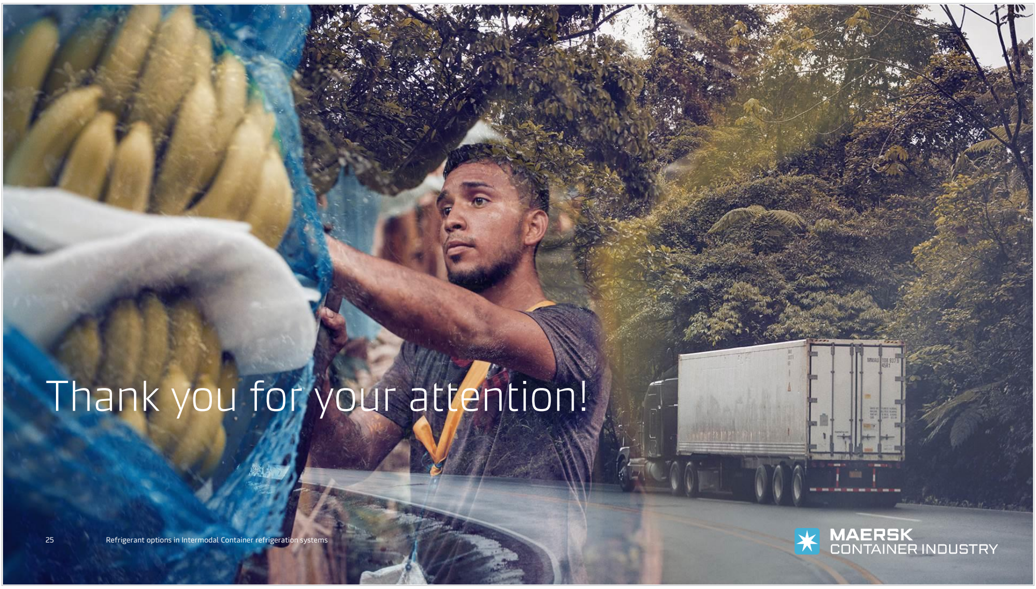
Thank you for your attention!
25
Refrigerant options in Intermodal Container refrigeration systems
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Agenda

- About me
- Marine reefers
- The Star Cool Refrigeration system
- The measurement setup and data
- PV diagrams
- Speed sweeps
- Improvements
- Conclusion

Piston compressor tests, Refrigeration and heat pump symposium 2021.

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Classification: Internal

Kristian Fredslund

- Msc DTU Applied Mechanical Engineering
- IPU – Energy systems
- Danfoss – Refrigeration specialist (controls)
- Startup Refrigeration controls
- Independent consultant – Cool Consult

- Refrigeration, Thermodynamics
- Control engineering
- Programming
- Communication, auxiliary etc.

3 Piston compressor tests, Refrigeration and heat pump symposium 2021.

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Classification: Internal

The Marine Reefer

The worlds most versatile refrigeration system.

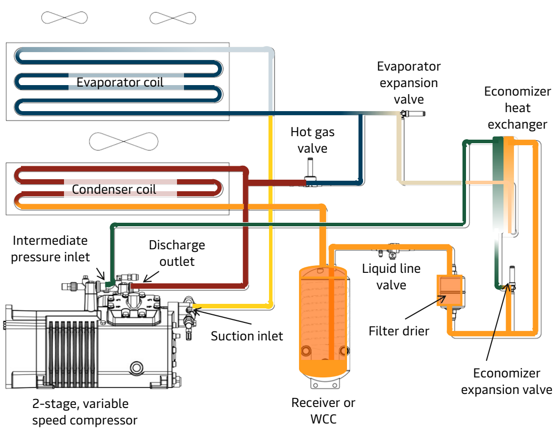
- Cool everything from pre-frozen fish to Durian fruits at +45 °C
  - Setpoints (inside box) -30..+30°C
- Operate around the globe
  - Environment (outside box) -40..+60°C
- Work under extreme conditions
  - Vibrations from trucks, trains, handling (70g drops)
  - Lists and tilting during operation
  - Salty humid environment
  - Unimaginable bad power supply (generator, ships??)
- Built to last 15 - 20 year lifetime
- Low budget
  - Every dollar counts in mass production (July 2021, unit 400.000 was produced)

Piston compressor tests, Refrigeration and heat pump symposium 2021.

MAERSK CONTAINER INDUSTRY

Classification: Internal

Cooling circuit



5 Piston compressor tests, Refrigeration and heat pump symposium 2021.

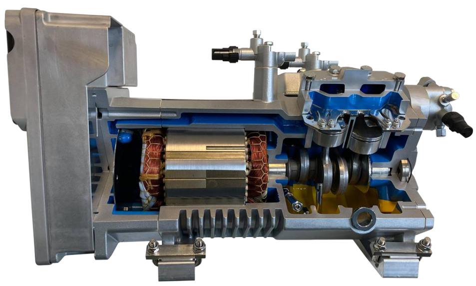
MAERSK CONTAINER INDUSTRY

Classification: Internal

The unique Star Cool compressor
With inverter

Variable Compressor Speed
= The Ultimate Capacity Control

- Frequency Converter
  – variable speed control
- 600 – 3300 rpm (20-110Hz)
- Two-Stage Reciprocating
- Lightweight Aluminium, only 58 kgs
- Maintenance-free, non-corrosive exterior



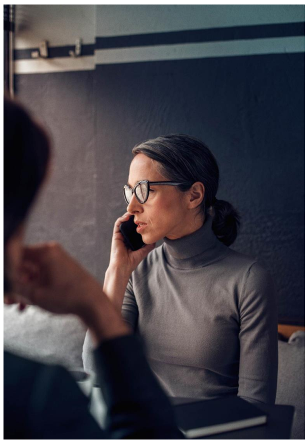
6 Piston compressor tests, Refrigeration and heat pump symposium 2021.

MAERSK CONTAINER INDUSTRY

Classification: Internal

The Task: compressor efficiency increase

- Efficiency?
  - Both isentropic (power consumption pr. compressed kg)
  - And volumetric (full speed capacity)
- 4 main parts to a compressor:
  - Motor
  - Drivetrain
  - Housing
  - **Valves (valveplate)**



7 Piston compressor tests, Refrigeration and heat pump symposium 2021.

MAERSK CONTAINER INDUSTRY

Classification: Internal

Close inspection of a valve plate

- Suction reeds
  - Valve losses -> under pressure in cylinder
  - Reduced capacity
- Discharge reeds
  - Valve losses –> over pressure in cylinder
  - Reduced capacity (re-expansion)
  - Extra work (expansion ≠ compression)

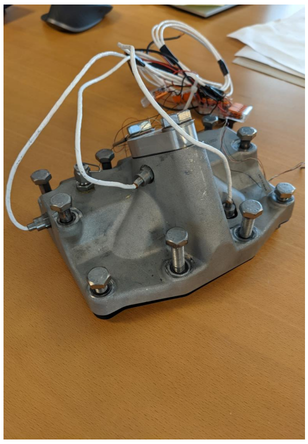
8 Piston compressor tests, Refrigeration and heat pump symposium 2021.

MAERSK CONTAINER INDUSTRY

Classification: Internal

Measurement setup

- Kulite pressure sensors
  - Absolute pressure sensors,
  - calibrated with N2 pressure on site in for each test series (minor adjustments)
- High speed DAQ
  - xxkHz sample rate
  - Xxx samples pr revolution at max speed

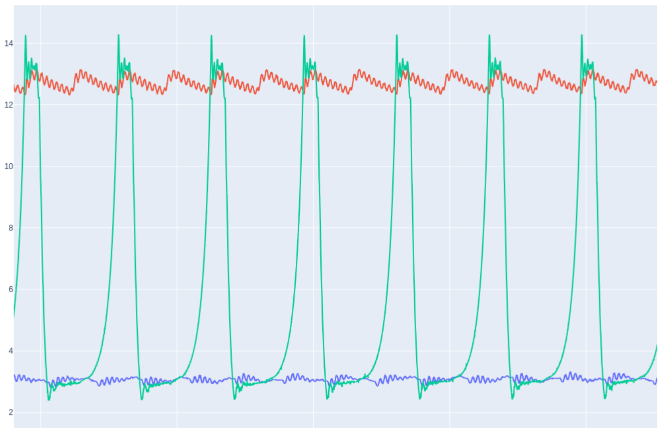


9 Piston compressor tests, Refrigeration and heat pump symposium 2021.

MAERSK CONTAINER INDUSTRY

Classification: Internal

Pressure curves (time series)



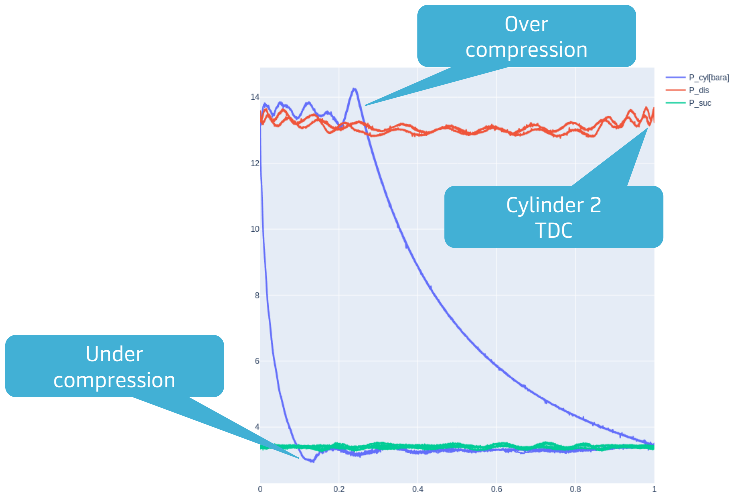
10 Piston compressor tests, Refrigeration and heat pump symposium 2021.

MAERSK CONTAINER INDUSTRY

Classification: Internal

PV-diagram

- 5 strokes in one image
- Piston motion equations
  - Conrod length
  - Crank angle
  - **Manual TDC assessment**

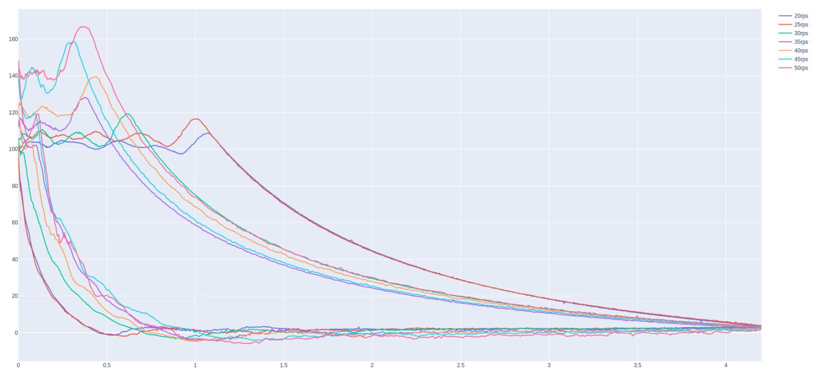


11 Piston compressor tests, Refrigeration and heat pump symposium 2021.

MAERSK CONTAINER INDUSTRY

Classification: Internal

PV diagram – speed sweep



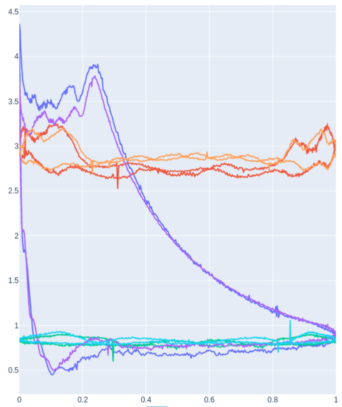
12 Piston compressor tests, Refrigeration and heat pump symposium 2021.

MAERSK CONTAINER INDUSTRY

Classification: Internal

30(purple) vs 40(blue) rps

- The last part of the speed costs..
- Next step is even more stressing for the system



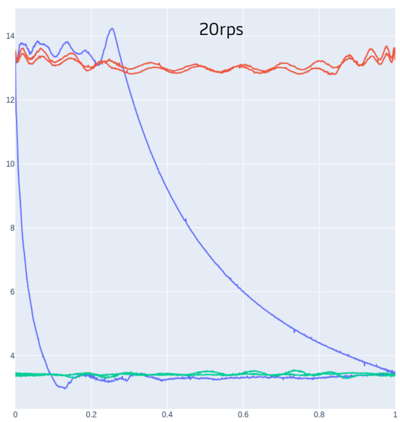
13 Piston compressor tests, Refrigeration and heat pump symposium 2021.

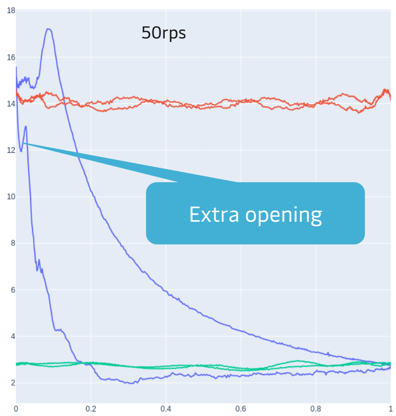
MAERSK CONTAINER INDUSTRY

Classification: Internal

Problem - theory

- Fluttering and/or bending of the valve causes one or more extra openings during the intake stroke





14 Piston compressor tests, Refrigeration and heat pump symposium 2021.

MAERSK CONTAINER INDUSTRY

Classification: Internal

Mitigation I stiffer valve plates

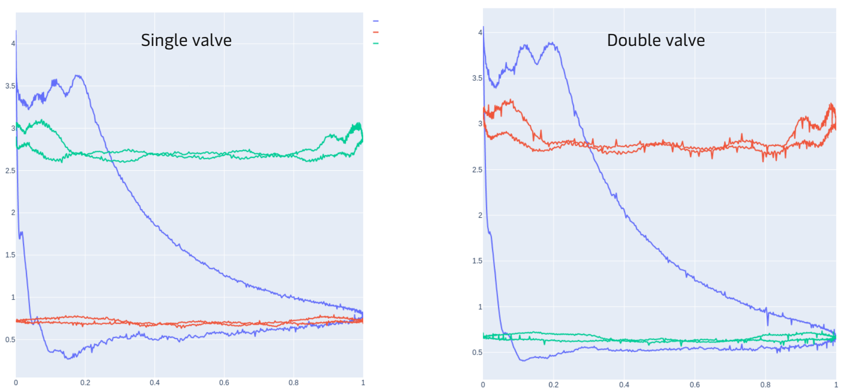
- As expected, did not help
- Also a valve plate with more narrow bend point was conceptualized (less stiff) but never tested.

15 Piston compressor tests, Refrigeration and heat pump symposium 2021.

MAERSK CONTAINER INDUSTRY

Classification: Internal

Mitigation 2 – dual valves (oil film)



16 Piston compressor tests, Refrigeration and heat pump symposium 2021.

MAERSK CONTAINER INDUSTRY

Classification: Internal

Summary and Conclusion

- A better understanding of the mechanical behind dropping efficiency was achieved
- Valves pressure losses was not the primary driver, re-opening was.
- In general, high speed is to be avoided when possible

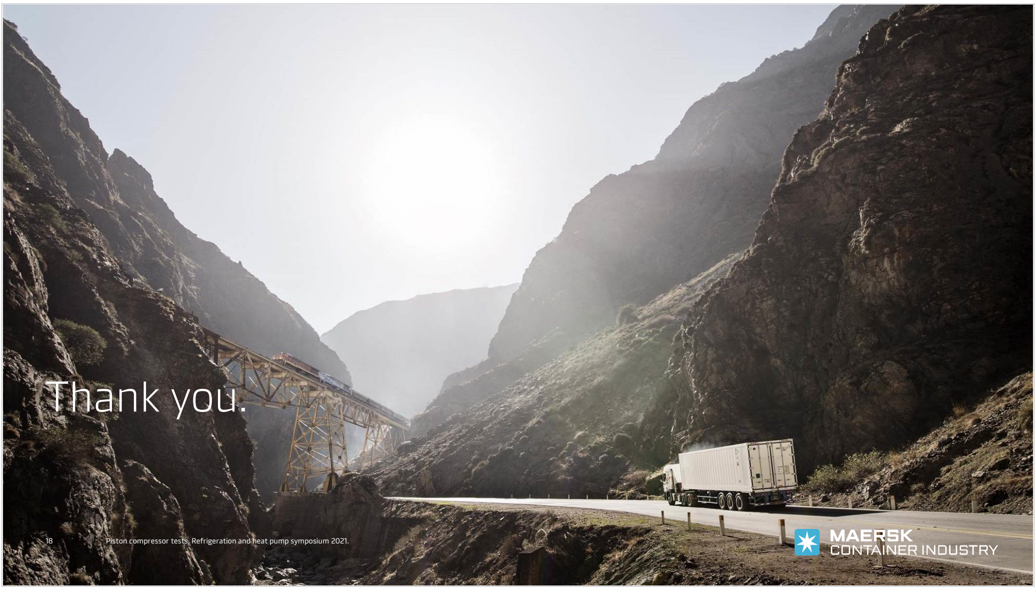
Next steps

- Durability dimension (50k run-hours no maintenance)
- Failing valves not related to runtime*speed.
  - Operating conditions
  - Can we estimate additional impacts under different operating conditions.

17 Piston compressor tests, Refrigeration and heat pump symposium 2021.

MAERSK CONTAINER INDUSTRY

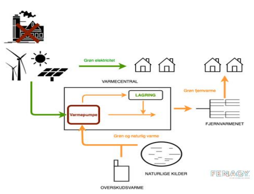
Classification: Internal

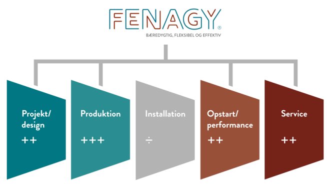


FENAGY PRODUCENT AF VARMEPUMPER OG KØLEANLÆG I AARHUS

- 4 stiftere + 21 medarbejdere
- CO_2 som kølemiddel/arbejdsmedie
- Varmepumper og industrielle køleanlæg (300 kW – 2 MW)
- Ingeniørkontor og produktion i Aarhus

- Fokus er på **Projekter**, hvor kundens behov er i centrum
- **Fabrik** der producerer de bedste industrielle systemer med support fra de bedste underleverandører
- Anlæg der sikrer de billigste levetidsomkostninger og billigste driftspris



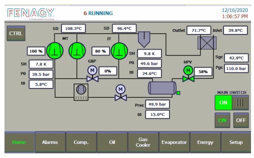


FENAGY

FENAGY

Produkter (Industrielt fokus H-serie and C-serie)

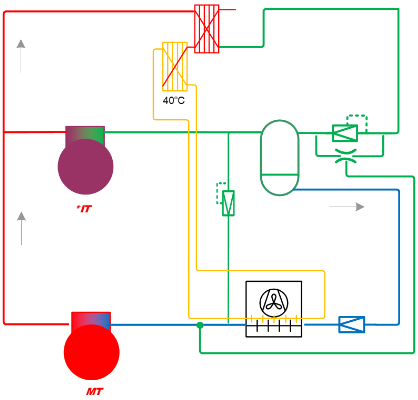
H300 | H600 - housed | H1200 | H1800

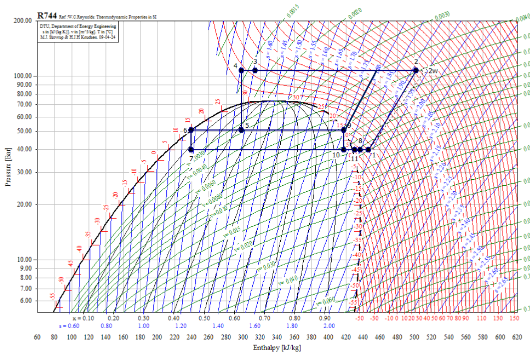


- Siemens PLC
- Standard program
- Integration af eksterne I/O

FENAGY

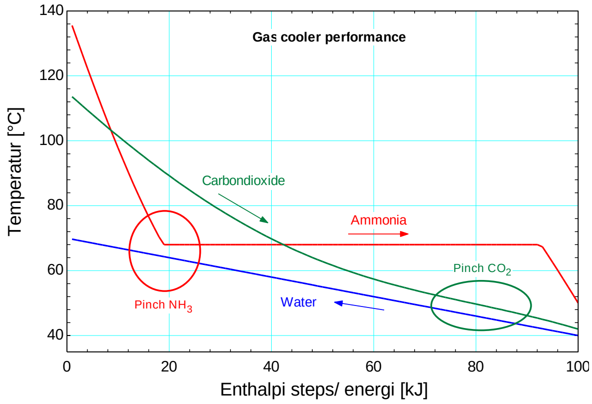
FENAGY
FLEXIBEL PRINCIPAL DESIGN



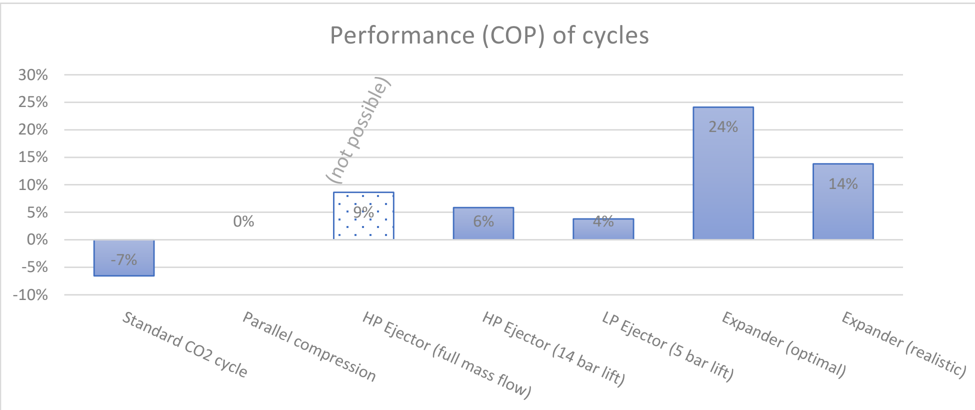


FENAGY

FENAGY VARMEAFGIVNING AF EN CO_2 VARMEPUMPE

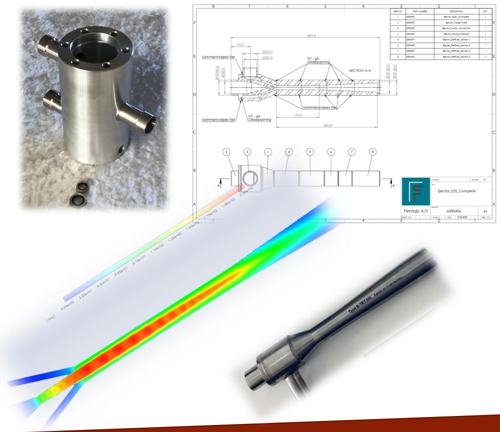


FENAGY PERFORMANCE OF SYSTEMS



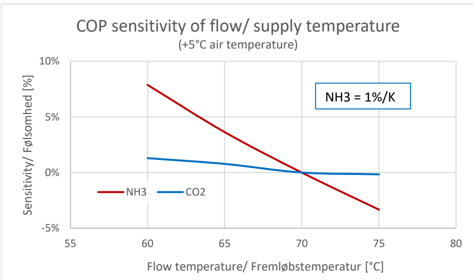
FENAGY UDVIKLINGSPROJEKTER

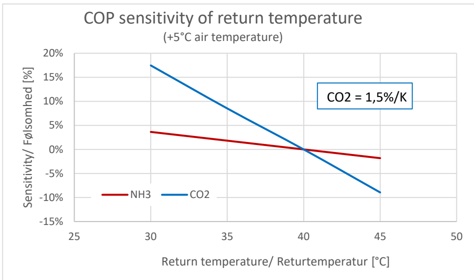
- **Ejektor**
  - Ejektor er allerede testet
  - Udvikling af ejektor med større kapacitet HP
  - Styringsalgoritme med ejektor
- **Ekspander**
  - Udvikling af prototype
  - Test på TI lige nu
- **Produktprogram**
  - Endnu bredere program (større anlæg)
  - H300
  - Køleprodukter



FENAGY

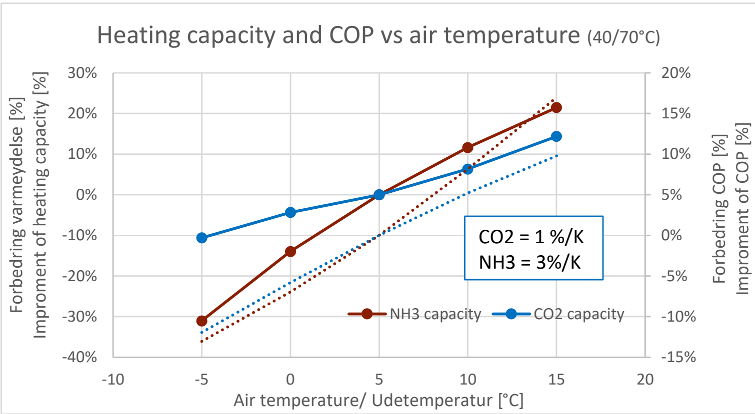
FENAGY FØLSOMHED FOR RETUR- OG FREMLØSBTEMPERATUR



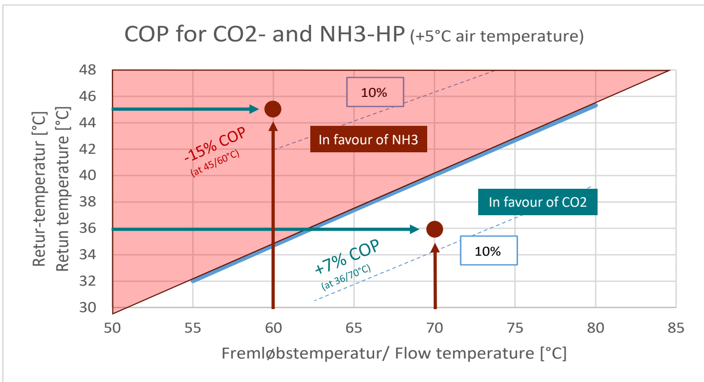


FENAGY

FENAGY FØLSOMHED FOR TEMPERATUR AF UDELUFT (RESERVOIR)



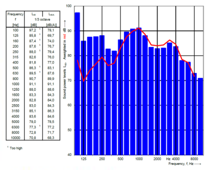
FENAGY SAMMENLIGNING MELLEM CO_2 OG NH_3 VARMEPUMPER



FENAGY TEST VED TEKNOLOGISK INSTITUT

- Funktion af PLC – SRO
- Funktion af enkelt komponenter
- Performance af enkelt-komponenter (GK, evap, IHX, kompressor, olieuds)
- Performance af system inkl. tryktab
- Ejektor-test
- Lyd og vibrationer
  - Lpower = 98dBA, Lpressure = 40dBA (10 m), Lac = 25dB (max. 75 KB-vægtet)
- Kalibrering af beregningssoftware

Compressor side. Pos. A2-6 + above A7



FENAGY

FENAGY

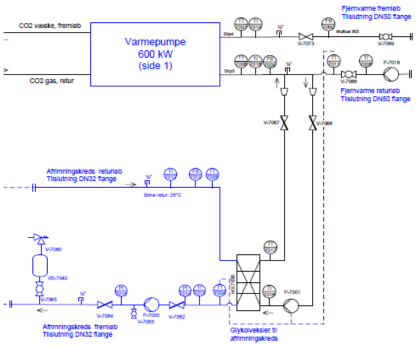
OVERVIEW HARLEV

- 4,6 MW halmkedel
- 2x6 MW oliekedel
- 1x600 kW varmepumpe (H600-AW)
- Energioptag fra luft
- Test af installation - hurtig
- Måling af lydniveau 40 dBA (10m)
- Kapacitet og COP
- Funktion af fordampere
- Afrimningsfunktioner

FENAGY

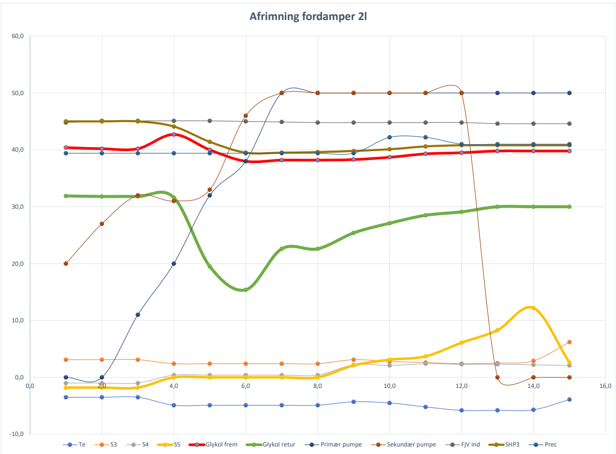
FENAGY AFRIMNINGSTEST

- Behovsstyret afrimning
- System-design og styring
- 5 og 6 mm finneafstand
- Epoxy fins eller AlMg
- Forskellige afrimningskredse
- Optimering af afrimnings-sekvens
  - Pump-down
  - Defrost
  - Drain
  - Drip
  - Fan delay
- Nye metoder
  - Styring af blæsere under afrimning (reversering, S3+4)
  - Tid mellem afrimninger – flere metoder testet
  - Afrimningstid – stop – flere metoder testet



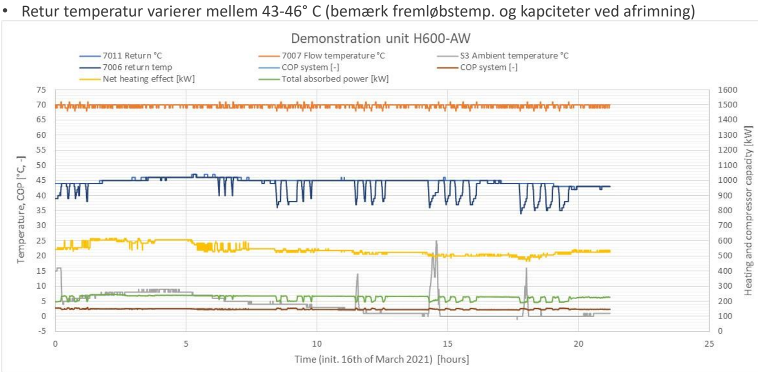
Målepunkter og styringsparametre per fordamper

- Dx fordampning (altid CO2 i fordampere)
  - Mange målinger per fordamper
  - Robusthed for variationer i vind og vejr
  - Lav kølemiddelfyldning
- Fordampertryk (T_e)
- Lufttemperatur ind (S3)
- Lufttemperatur ud (S4)
- Finnetemperatur (S5)
- Åbningsgrad ventil
- Plus et par andre



FENAGY Måledata H600 – vinterdrift med afrimning

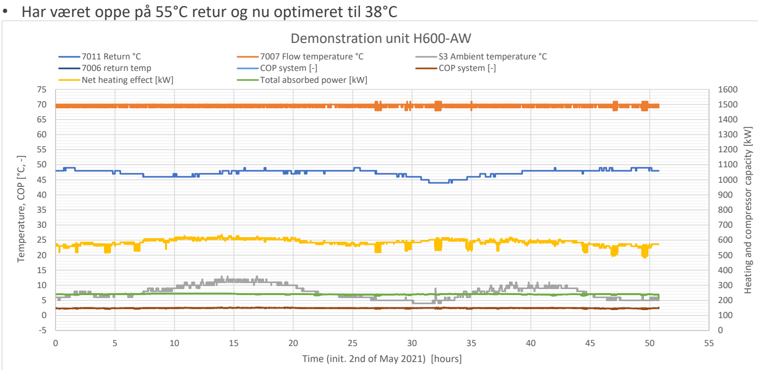
- Peaks på sensor 7006 og S3 føler skyldes afrimning
- Retur temperatur varierer mellem 43-46° C (bemærk fremløbstemp. og kapciteter ved afrimning)



FENAGY

FENAGY Måledata H600 – forårsdrift med høj retur temperatur

- Retur temperatur varierer mellem 44-49° C
- Har været oppe på 55°C retur og nu optimeret til 38°C



FENAGY

FENAGY Start/stop af varmepumpe

- Hvor stor skal en varmepumpe være?
- Skal den kun køre når strømmen er billig?
- Fast eller afbrydelig strømforsyning
- Regulerkraft / systemydelser
- Hvor hurtig kan en Fenagy varmepumpe starte og stoppe?


Industrial Refrigeration Cooling, Heating and Energy Solutions
Heat pumps:
De sidste års erfaringer med industri varmepumper - udvikling og fremtid
The power behind your mission
Johnson Controls


Heat pumps:
De sidste års erfaringer med industri varmepumper - udvikling og fremtid
Presentation flow:
1: JCI background as heat pump supplier
2: Overlook 2011-2021
3: Experiences 2011-2021
4: Future >2021
The power behind your mission
Johnson Controls


01
JCI background as heat pump supplier

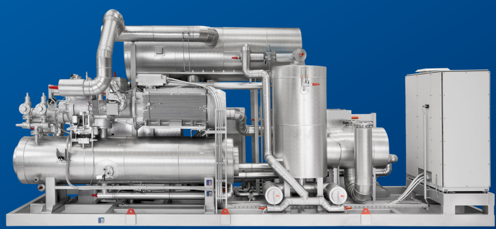

Solutions built on industry leading products
We are a leading OEM supplier of reciprocating and screw compressors, chillers for standard and low temperature applications, heat pumps, and control systems.


Our Markets
Food and beverage
Chemical and petrochemical
Utilities
Pharma and healthcare
Distribution and storage
Leisure and sports
High-tech
Other industries


Full Lifecycle Solutions focus !
We understand the European market and its dynamics thanks to our long lasting presence.
We design the applications with a custom approach to our customer needs.
We offer design and engineering of solutions
We help customers with aftermarket solutions, spare parts and ensure their performance
Development and Manufacturing
Reducing complexity, streamlining collaboration
Solution design
Tailored solutions to win every time
Installation
Dependability guaranteed
Service
Lifelong performance enhancements

02

Overlook 2011-2021



Heat pumps portfolio

YORK PROCESS SYSTEMS

Fully Customized Industrial Products

YMC2 HP
- Water up to 65°C
- Heating capacity: 1,600 – 3,000 kW
- Variable Speed Centrifugal,
- Magnetic Bearings, R134a and R513a

YK
- Water up to 50°C (Std) / 70°C (HP)
- Heating capacity: 1,000 – 9,000 kW
- Centrifugal compressor, R134a and R513a

CYK HP
Centrifugal compressor / R1234a
- CYK HP Hot water up to 90°C
- Heating capacity 2500 - 7000 kW

Titan OM HP
Centrifugal multistage compressor / R1234a
- Titan OM HP hot water up to 93°C
- Heating capacity 5000 - 20000 kW

SABROE

Fully Customized Industrial Products

HeatPAC HPC recip
- Water up to 75°C
- Heating capacity: 200 - 2000 kW
- Recip compressor, fixed or variable speed
- Ammonia (R717) (<50 kg charge)

HeatPAC HPX recip
- Water up to 90°C
- Heating capacity: 100 - 1400 kW
- Recip compressor, variable speed only
- Ammonia (R717) (<50 kg charge)

DualPAC
- Water up to 90°C
- Heating capacity: 400 - 2000 kW
- Recip compressor, fixed or variable speed
- Ammonia (R717)

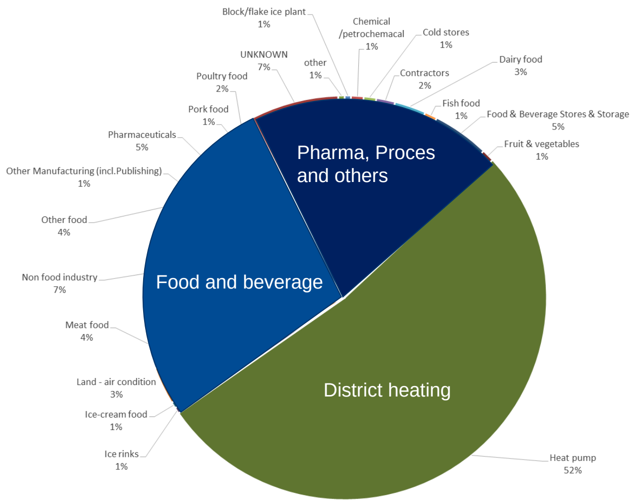
Customised heat pumps
- Water up to 75-95°C
- Heating capacity: up to 13000 kW
- Screw compressor, variable speed only
- Ammonia (R717)

So how did we do on heat pumps last 10 years ?

Segments

- **Split per segment 2010-2020…**

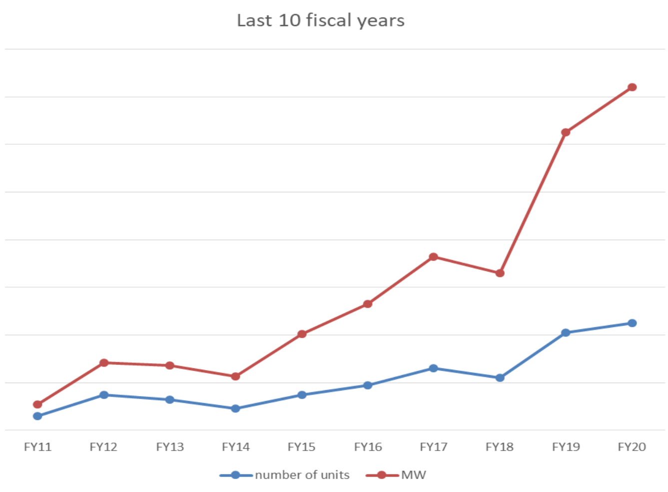
- **- District heating ~55%**
- **- Food and Bev ~25%**
- **- Others 20%**



Market evolution over the last 10 years

- **Unit size have increased**

- **Average annual growth**
- >10%YOY on units
- >20% YOY on revenues

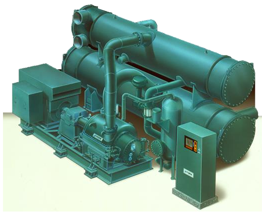


03

Experiences 2011-2021
Cases and technology reference
- Centrifugal
- Screw
- Reciprocating

District heating & cooling

Paris La Défense, France



Simultaneous production of heating and cooling

Installed 2012-2013, operational since 09-2013

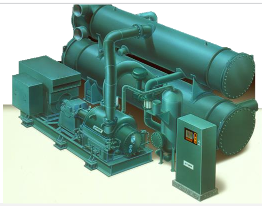
- Annual operation hours at full load 7500h,
- Total hours covered in years ~51.000hours

- Experience
  - Refrigerant leakage less than 2% yr.
  - Compressor haven't been serviced yet,
    - maintenance schedule on vibration measurements succesfull
  - Annual cleaning of S&T heat exchangers. Even though is a closed loop system there is a COP drop over the year, but after cleaning return to nominal
  - Annual exchange of sensors and gauges significantly reduce unintended stops to zero
  - Compressor robustness very high !!!

CENTRIFUGAL COMPRESSORS

Learnings top 3

- Switch from R134a to R1234ze have been successful
  - Very few modifications have been done to make the compressors fit for HFO
  - Same goes for auxiliary equipment
- Service receiver
  - Synth. Refrigerants are not in-expensive. For each unit is it highly recommendable to install a service receiver that can contain the full charge.
  - Up to 8.000kg refrigerant charge is a lot of bottles !
- Vibration monitoring
  - Vibration level as the threshold of service of compressor successful. No breakdowns



Centrifugal compressors have over the last decade moved from

Refrigerant:

In the start it was R134a, today they are all offered with R1234ze. Refrigerant prices on HFO have been stable and is not regarded "as expensive" anymore as prices have dropped.

Capacity:

Low GWP HFO refrigerants give slightly lower capacity so capacity have been reduced ~10% to 22.000kW

Temperature:

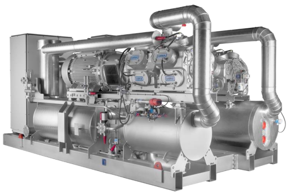
With R134a was the centrifugal limited on temperature to ~65-70°C and also limited in lift.

With R1234ze is the outlet moved to 90-92°C and lifts easy 85K

RECIPROCATING COMPRESSORS

District heating

Denmark



Production of heating from effluent water

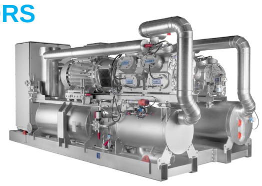
Installed 2017, operational since 09-2017

- Annual operation hours at full load 5000h, Total hours covered in years ~20.000hours
- Experience
  - Evaporating pressure fluctuation critical for liquid hammer
    - Importance of super heating and control loops to limit the temperature increase K/s
  - Density of ammonia
    - System with big variation on evaporating temperature and a small fixed refrigerant charge is sensitive due to the density. Cold evaporation lack of refrigerant, High evaporation too much charge
  - Heat exchanger fouling
    - Effluent water side sensitive, and filter technology and CIP important
    - Oil fouling on evaporators need to be taken into account in performance/COP or oversize to compensate

RECIPROCATING COMPRESSORS

Learnings top 3 (+1)

- Reciprocating 50/60 bar compressors with up to 90°C condensing temperature have proven to be reliable.
  - Focus on vibration contributes positively to service intervals and obtained reliability
  - Top cover cooling increases valve plate lifetime and contributes positively to service intervals
- Synesthetic oils have a low vapour content with high discharge temperatures and reduces oil carry over and reduces fouling on evaporators
- Part load purely on VSD will keep the vibration level to a minimum
  - DO NOT use disengaging of cylinders !
- Water heating/tracing of compressor, top covers and insulation enclosure can be an advantage and prevent refrigerant pocket during st.by.



Reciprocating compressors have over the last decade moved from

Refrigerant:
Development has primarily been for Ammonia
HFO refrigerants is NOT adapted for recips

Capacity:
Capacity on available compressors have moved from
- ~1000 to ~2.500kW at 50bar
- ~ 0 to ~1.500kW at 60bar

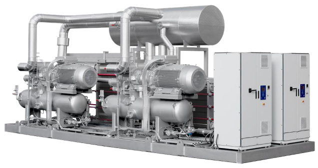
Temperature:
Adaptation of condensing pressure from 40 to 50 - 60bar equals increase in condensing temperature
- 65-73°C
- 65-90°,

Discharge temperatures increase from 110- 150°C

SCREW COMPRESSORS

Central heating from effluent water

Norway



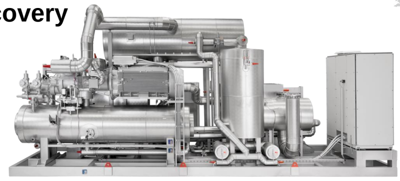
Production of heating from cold effluent water

Installed 2013, operational since 09-2013

- Annual operation hours at full load as heat pump est. 3500h, Total hours covered in years ~25.000hours
- Experience
  - Low temperature heat pump operation on 28bar / 55°C as a twin unit un-problematic
    - Parallel operation on VSD in part load important to run synchronous rpm on the two compressor
  - Heat exchanger fouling
    - Plate heat exchanger in titanium with back-flush and CIP proven to be reliable towards effluent water
    - Effluent water side sensitive, and filter technology vital.
      - Bernoulli's filters may not always be the best technology choice !
      - Automatic backwash plate type filters may be a viable alternative

SCREW COMPRESSORS

District heating and heat recovery
Denmark



Production of heating from data center

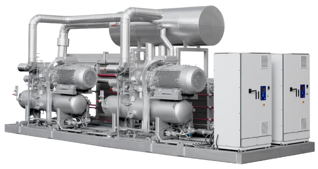
Installed 2019, operational since 09-2019

- Annual operation hours at full load as heat pump est. 6.000h
- Experience
  - Superheating of suction gas is important to have a reliable and durable compressor
    - On the expense of performance but essential for keeping up bearing lifetime
    - Essential for keeping up unit up-time commitment
  - Refrigerant pockets
    - Compressor equipped with heat tracing so it doesn't act as a “condenser” during st.by.
      - Refrigerant can be trapped and damage bearing in start up
  - Mass flow in high pressure compressors is high. High mass flow makes unit more sensible to vibrations
    - Vibration measurement of motor, compressor & pipes is an important tool to prevent down time

SCREW COMPRESSORS

Learnings top 3

- Focus on vibration contributes positively to service intervals and obtained reliability
  - Mass flows in compressor ~x3 mass flow in refrigeration. Heat pump compressors are more sensitive to vibration
  - VSD operation and vibration monitoring go hand in hand.
- Choice of oil is important
  - Synth. oil have a low vapour content with high discharge temperatures and reduces oil carry over and reduces fouling on evaporators
  - Oil type is important for screws as oil at high pressures contain ammonia, and affect the lubrication consequently bearing life
- Stand by heating and start up procedures
  - Stand by heating and to avoid condensed liquid in compressor block needs attention
  - Start up must be “gentle” allow the complete heat pump minimum 20 min before cut in on heating grid



Screw compressors have over the last decade moved from

Refrigerant:
Development has primarily been for Ammonia
HFO refrigerants is adapted for screws, but no significant installed base

Capacity:
Capacity on available compressors have moved from
- ~0 to ~8.000kW at 40bar
- ~0 to ~7.000kW at 60bar (NEW !!!SAB 273S HP)

Temperature:
Adaptation of condensing pressure from 28 to 40 - 60bar equals increase in condensing temperature
- 55-75°C,
- 55-93°C,

Discharge temperatures increase from 85-110°CC

Other learnings top 5

Suction gas superheating:
To avoid liquid hammers and rattling is suction gas superheating of 3-5K essential agreeable among all leading compressor manufactures.
It is at the cost of performance ~2-3%
- what is most reliable a Skoda or a Ferrari ?

Energy absorbers:
5-10% of the heating capacity goes into defrosting of energy absorbers when ambient temperatures is between +5 to -5°C
Be aware of short circuit of air in, and equip installation with air tight walkways. Short circuit can easily be -1K so remember to add this in design phase.

Vibration:
INSTALL VIBRATION EQUIPMENT, and do vibration commisioning during start up.

Controls:
Remember to make loops SLOW and installation of buffer vessels if possible.
The very fast control loops we have as a legacy in refrigeration create trouble in heat pumps.
Keep temperature fluctuations below 1K/10min

Promise and deliver… tolerances:
Un-mature market and technology have made all manufacturers strive for performance, so if possible do a factory acceptance test. But for the Site acceptance test is:

Essential that tender material describe the measurement method and tolerance.

Tolerance on heat pump equipment can be without significant additional cost be:
COP: - 3 to 4% and Heating capacity 0%
Measuring equipment tolerances in the 3% range.
The contractual part can be clear. As example:
Penalties below 97% capacity
Penalties below 94% on COP

04

Future >2021

Future for heat pumps best guess

Short term: 5years

Prototype in 140°C heat pumps
Successful heat pumps at ~95°C Screws
Boom in the projects with waste heat in process industries
Pilot projects in the 50-100MW, unit size 20-25MW

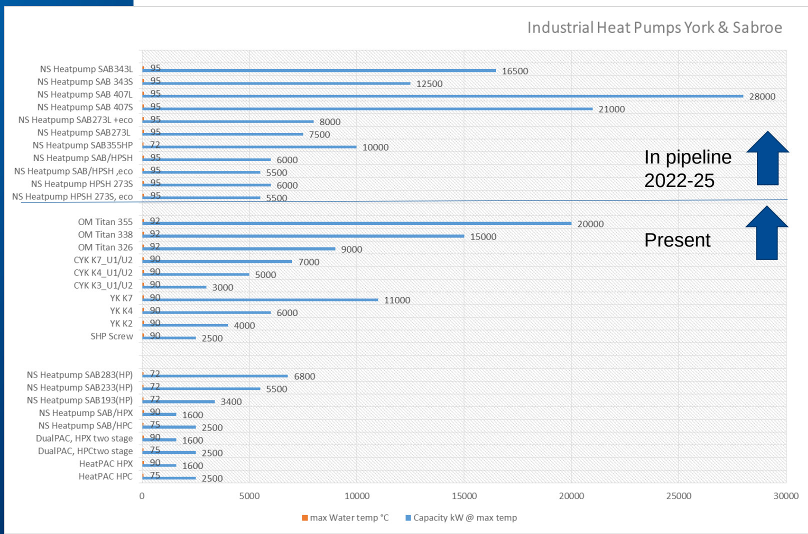
Mid term: 10 years

Prototype in 180°C heat pumps
Successful heat pumps at 140°C
Boom in the heat pumps used in other green tech processes
Environmental awareness on synthetic refrigerants.

Long term: 15 years

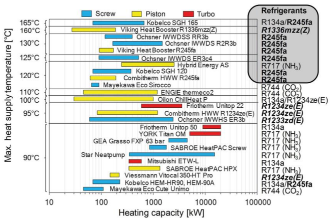
Successful heat pumps at ~180°C for process
District heating transmission grids <100°C after building renovation
+30% EU coverage of space heating with heat pumps

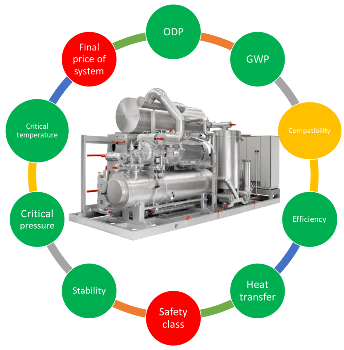
Heat pumps portfolio



Future for heat pumps best guess

Slide illustrations from Alexanders presentation yesterday





Thank you

The power behind **your mission**

Johnson Controls

Køle- og varmepumpeforum 2021

Lars Hjortshøj Jacobsen

ATES A/S

ATES anlæg – En nøgle til rentabel og bæredygtig samproduktion af køle- og varmeenergi

13-10-2021 Præsentation af ATES A/S ATES AQUIFER THERMAL ENERGY SYSTEMS

ENVATEK

ENVATEK ENERGI VAND TEKNIK

Vand & Teknik

INGENIØR HUSE Ingeniørrådgivning med garanti

ATES AQUIFER THERMAL ENERGY SYSTEMS

ENVATEK er en vand- og energispecialiseret koncern med tre selvstændige kompetenceprofiler samlet under fælles ejerskab.

Vand & Teknik A/S, ATES A/S og Ingeniør Huse A/S har en vision om at rådgive og etablere "Grønne løsninger, bygget på ordentlighed", og arbejder indenfor et felt med rådgivning og projektering samt levering af fremtidens bæredygtige anlæg indenfor vandforsyning, energiproduktion og lagringsløsninger på fjernvarme- og køleområdet.

De tre selskaber er selvstændigt fungerende selskaber med hver sit markedsområde, men med en indbygget smidighed på grund af fællesskabet, der gør at alle aktiviteter og opgaveløsning udføres landsdækkende af specialister på tværs af ENVATEKs organisation – til stor gavn for vores kunder.

ENVATEK beskæftiger ca. 50 mand og arbejder ud fra hovedkontoret i Aarhus samt afdelingskontoret i København.

Vi har egne maskin-, automatik-, bygnings-, energi- og el-ingeniører ligesom vi har eget rustfast værksted montører og driftspersonel.

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ENVATEK – aktuelle projekter

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Hvorfor står jeg her i dag…?

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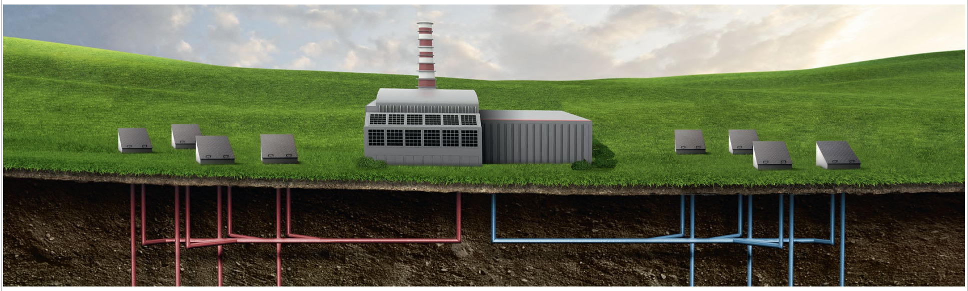
Set udefra…

- Da jeg for 8-10 år siden stod foran jer sidst på Danske Køledage i Odense…
  - "Virker det", "vi har hørt", bom, bom, bom, bom
  - Jeg har undersøgt sagen og kan nu svare - ja, det virker…
- Hvor har I/vi bevæget jer hen siden…?
  - Er markedet for jord/grundvandsbaserede så anlæg eksploderet…?
  - Har køle/varmepumpemarkedet fundet en anden vej at effektivisere løsningerne på…?
  - Med energi og klimamål for øje, kunne man så ikke lave nogle mere effektive løsninger ved at kombinere…?



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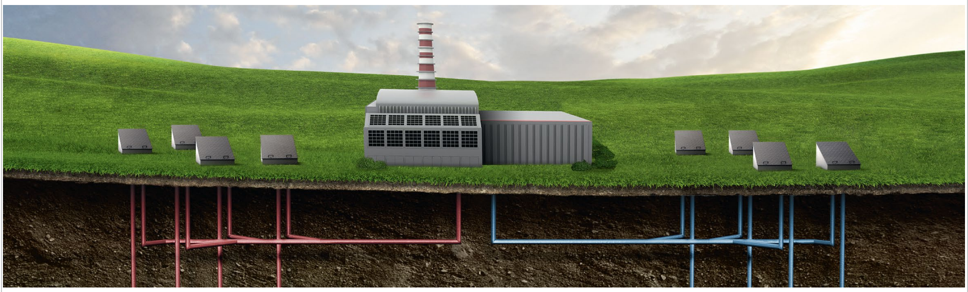
Min agenda…

- At få rykket på nogen af fordommene
- At forsøge at flytte jer og sætte gang i en diskussion
- At forsøge at give inspiration til mere bæredygtige løsninger, hvor vi for alvor kan nedbringe energiforbruget og bidrage positivt til den grønne omstilling
- Er det muligt…?
  - Hvis man ikke prøver, så flytter man intet



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What is ATES and why talk about geoenergy?

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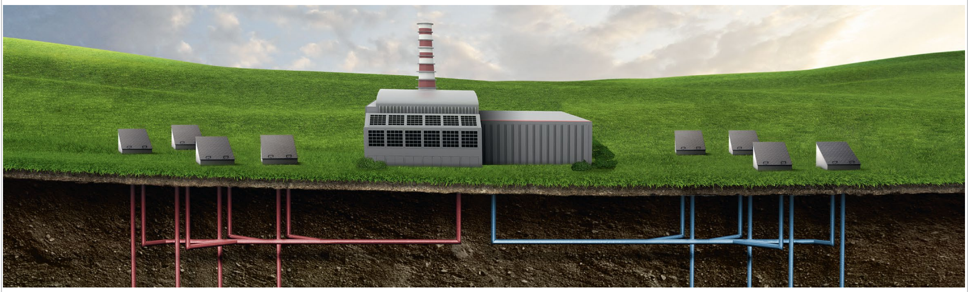
What is ATES?

- Aquifer Thermal Energy Systems
  - Groundwater cooling
  - Groundwater heat pumps
  - Thermal Storage in aquifers
- A combination of groundwater resource and mechanical cooling/heat pumps
  - Optimum between natural resource and machine installation



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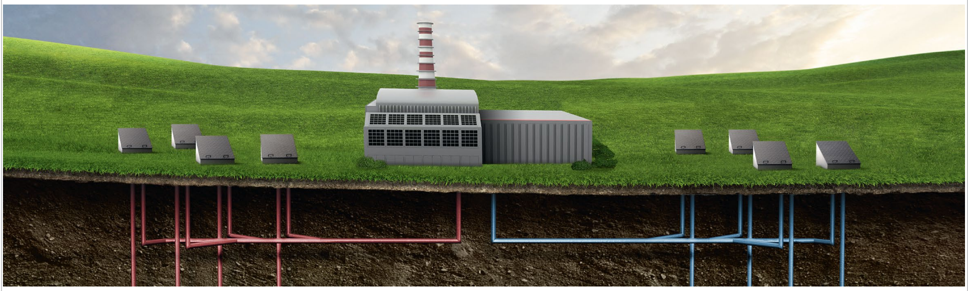
Why talk about geoenergy – eg ATES

- Sustainable solutions, with low energy composition, low operation costs and relative low ROI
- A trustable source for heat pumps and cooling
- Known and proven technology, which can be standardized
- Possible to establish even in narrow and sparse areas
- Very use full for storing large amounts of thermal energy with a relatively small energy loss



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Principales and different types

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Different types

Shallow:

Groundwater Cooling — Thermal Energy Storage (Low Temperature)

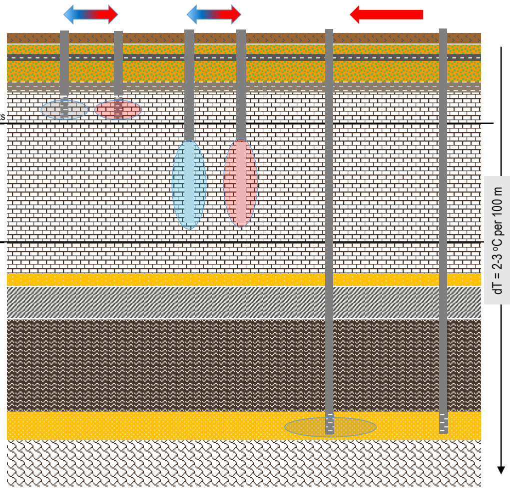
Groundwater Heat Pump

Semi deep

Low Temperature Geothermal Heating — High Temperature Heat Storage

Deep

High Temperature Geothermal Heating



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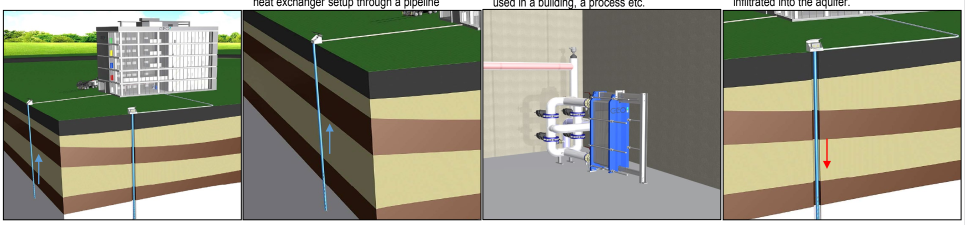
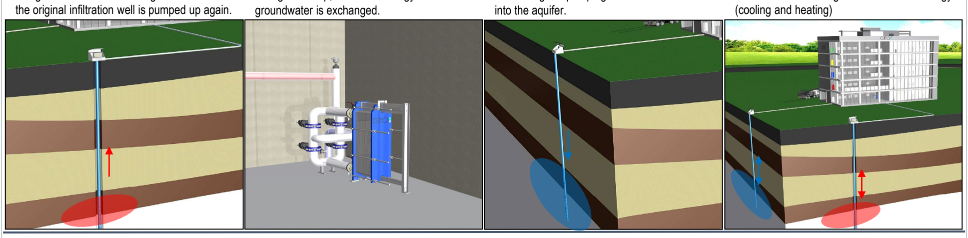
ATES - Principals

One way ATES system | Groundwater is pumped from an aquifer through a well into the system and led to a heat exchanger setup through a pipeline | Energy (eg. cooling) from the groundwater is exchanged through the heat exchanger and used in a building, a process etc. | The now warm groundwater is then led through a pipeline to an infiltration well and re-infiltrated into the aquifer.



The direction of the flow can be reversed meaning the warm re-infiltrated groundwater from the original infiltration well is pumped up again. | The groundwater is led through the heat exchanger setup, where energy from the groundwater is exchanged. | The groundwater is then led through a pipeline to the original pumping well and re-infiltrated into the aquifer. | This gives a two way reversible ATES system for seasonal storage of thermal energy (cooling and heating)



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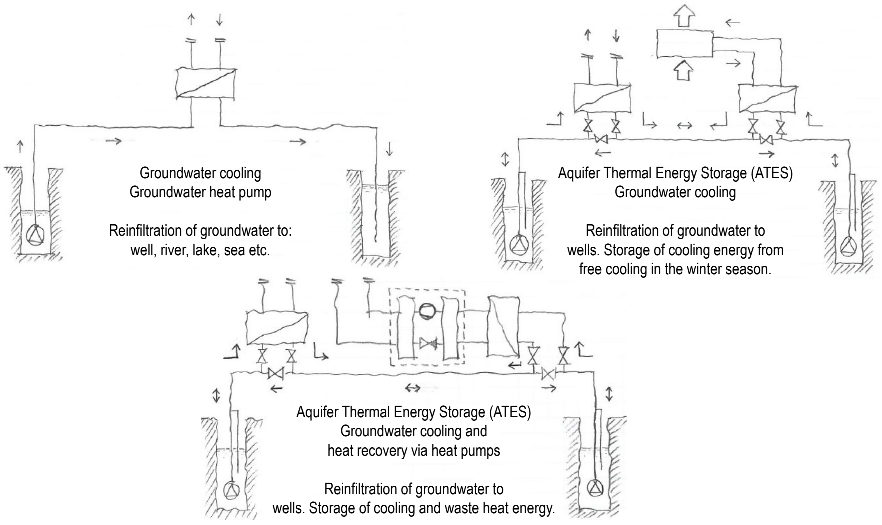
Principals



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Barrierer, lovgivning og myndighedshåndtering

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Barrierer – identificerede

- Manglende kendskab til anlæggene og driftserfaringer
  - Fagskel – Naturfaglig vs. installations-/køl-/VP- ingeniører
  - Forbehold – Rygter og manglende viden
- Risikoafdækning
  - Omkostninger up-front til forundersøgelser - prøveboring mv.
- For-/myndighedsarbejde
  - Virker for lægmand meget tungt
  - Kommer for sent i gang
- Projektbekendtgørelsen
  - Blokvarme – 250 kW

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Barrierer – what to do about them

- Manglende kendskab til anlæggene og driftserfaringer
  - Dialog med branchens aktører – facilitator mellem fagskel
- Risikoafdækning
  - Forventningsafstemning med bygherre og myndighedsdialog
  - Logisk og risikoafstemt forundersøgelsesprogram
- For-/myndighedsarbejde
  - Inddrag erfarende folk fra start
  - Start projektet op fra den rigtige ende
  - Hav respekt for miljølovgivningen
- Projektbekendtgørelsen
  - Dispensationsansøgning – Fortrængning af spidslast

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Lovgivning og myndighedshåndtering

- Lovgivningen er rimelig klar, men kompleks for lægmand
- Lovgivningen og håndtering minder rigtig meget om indvinding af grundvand til drikkevandsformål
- Ofte ses udfordringer og manglende forståelse mellem fagskel, der ikke naturligt samarbejder

- Myndighedshåndtering er generelt veludført og begrundet
- For sagsbehandler er det dog ofte "first time", og der kan derfor være lidt vaklen.

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Myndighedshåndtering

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Det handler om styring og rettidig omhu

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Proces

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Cases
Synergier og sektorkobling

Rentabel og bæredygtig samproduktion af køle- og varmeenergi

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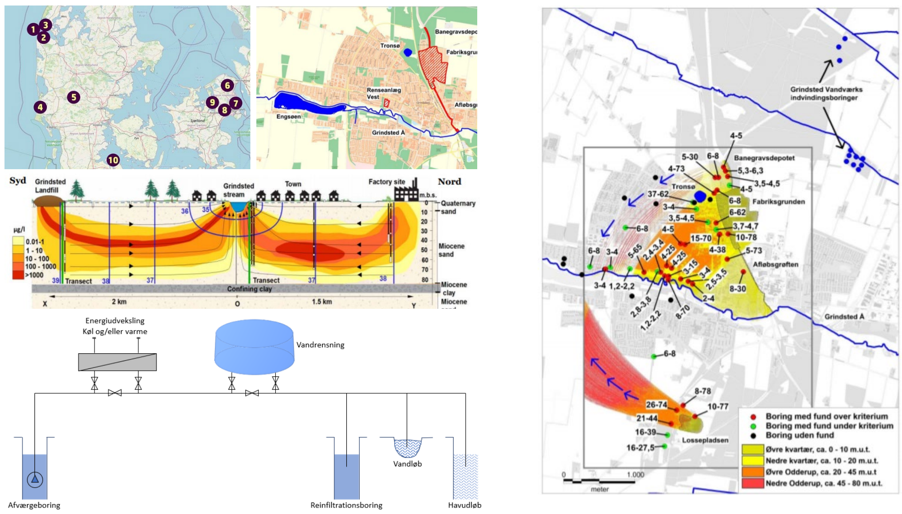
GEV - generationsforureninger



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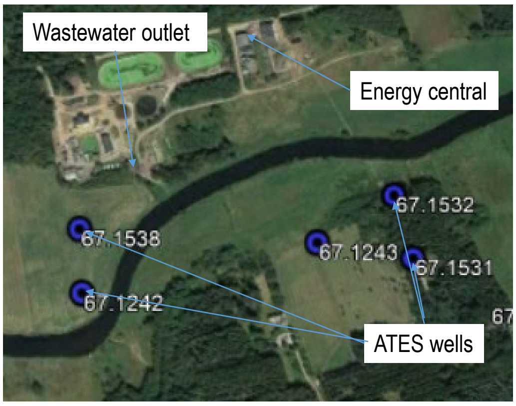
GUES – Wastewater & ATES heat pump

Demonstration site



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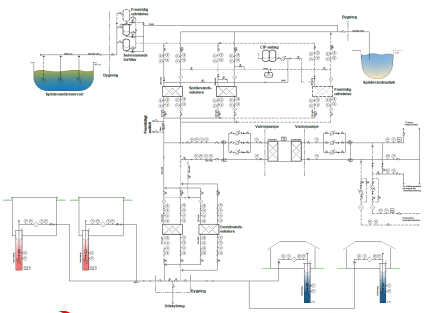
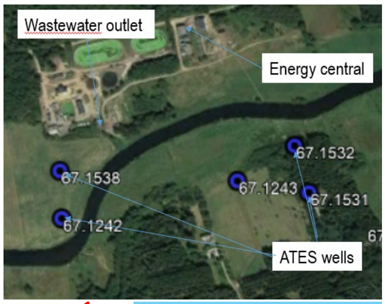
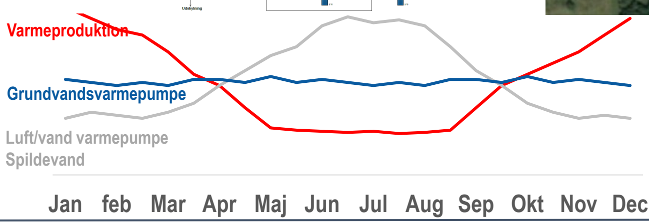
GUES – Wastewater & ATES heat pump







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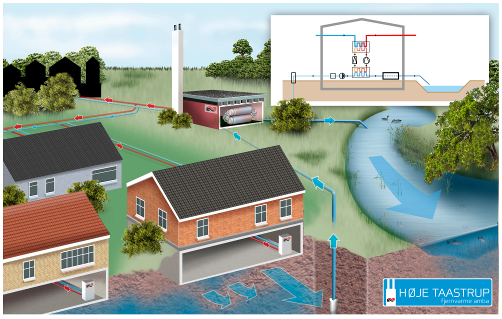
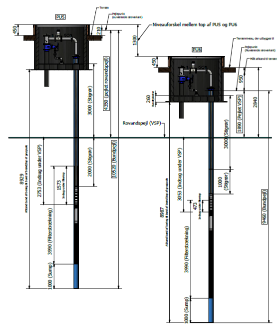
HTF – Mølleholmen





EuRefa

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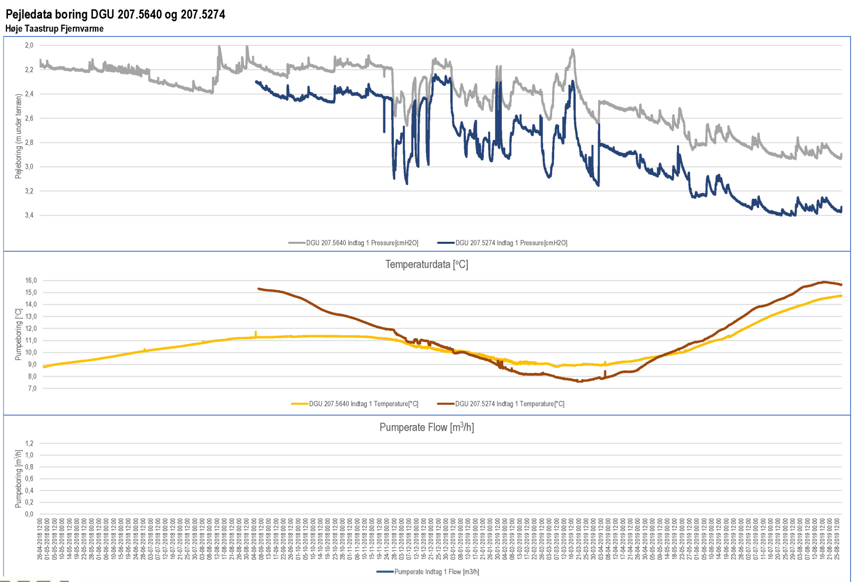

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AQUIFER THERMAL ENERGY SYSTEMS

Cases
De klassiske

Rentabel og bæredygtig samproduktion af køle- og varmeenergi

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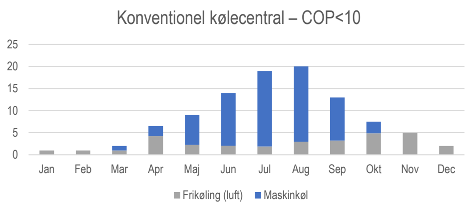
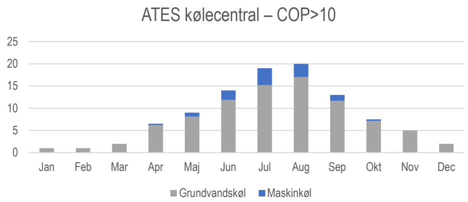
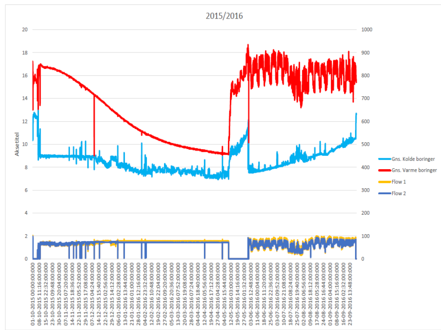
De klassiske







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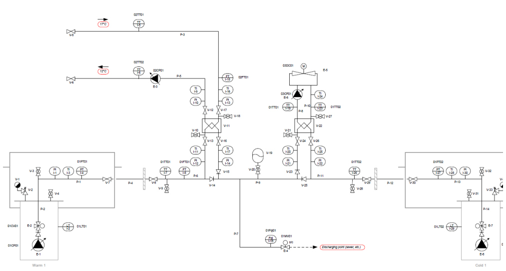
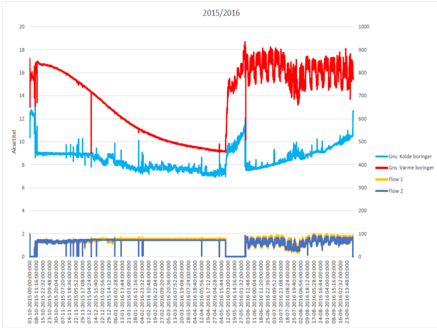
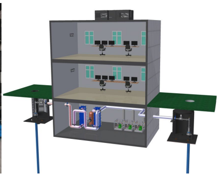
INTERXION







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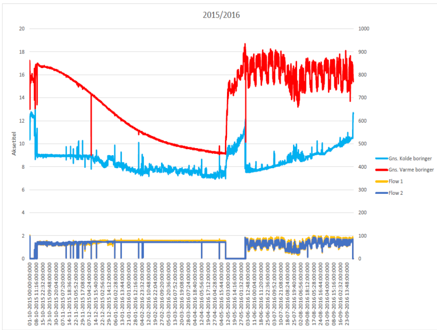
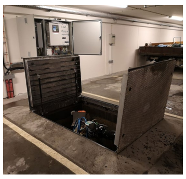
Copenhagen Towers

- Comfort, process and server coolin
- Established: 2009 / Rebuild in 2019
- Installation costs: 20-22 mio. dkr.
- Cooling & heating effect: 4,2 & 2 M
- Energy savings: >3 GWh per year.
- ROI: 5-7 years



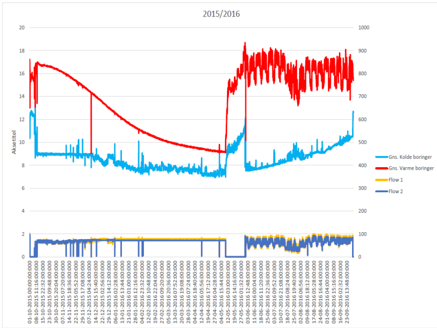


GEA

ATES
AQUIFER THERMAL ENERGY SYSTEMS

Hoeje Taastrup Fjernvarme a.m.b.a

- District cooling and heating
- Established: 2018/19
- Installation costs: -
- Cooling & heating effect: 1,5 & 1,2
- Energy savings: -
- ROI: -

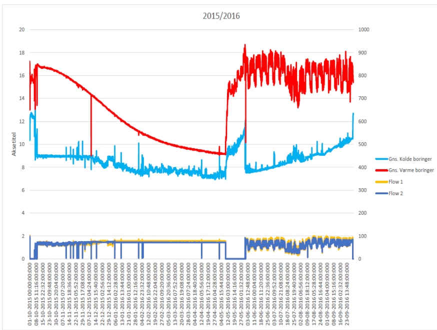


A Comfort

ATES
AQUIFER THERMAL ENERGY SYSTEMS

Goedstrup Hospital

- Process cooling without heat recov
- Established: 2018/19
- Installation costs: 11 mio. dkr
- Cooling effect: 1,5 MW
- Energy savings: 60-70%
- ROI: -



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Afrunding

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TAK FOR OPMÆRKSOMHEDEN

Lars Hjortshøj Jacobsen

ATES A/S

Hvad er det, der afholder os fra i højere grad at udnytte undergrunden til energiformål…?

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DANISH TECHNOLOGICAL INSTITUTE

"Low Charge Ammonia"

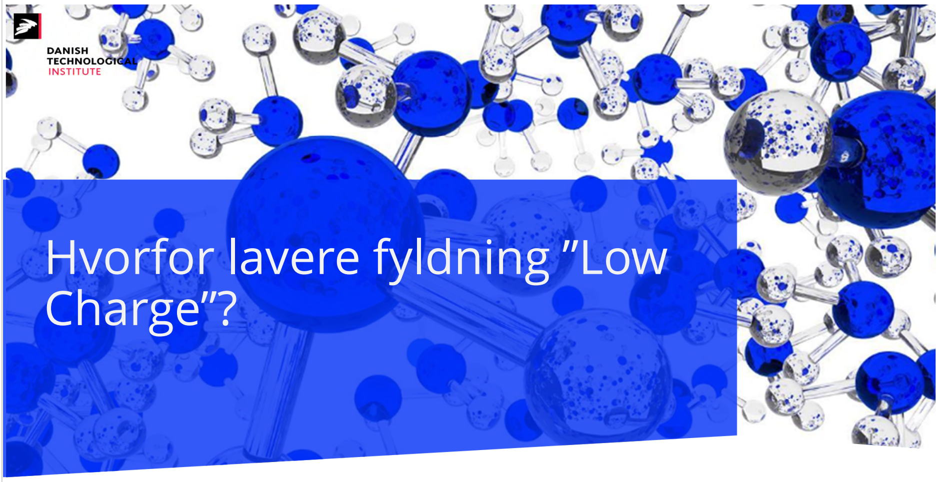
Fremtiden indenfor Industrielle ammoniak køleanlæg?

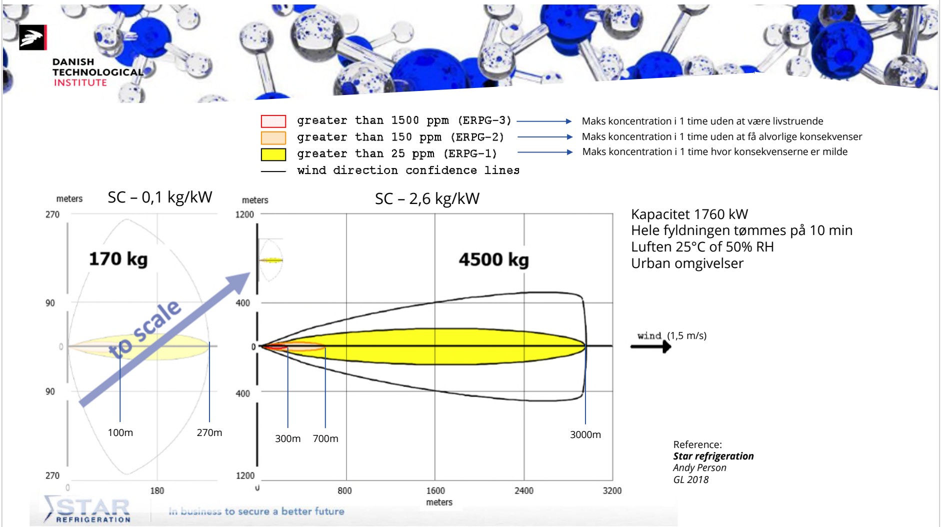
Køle- og Varmepumpeforum 04-10-2021

DANISH TECHNOLOGICAL INSTITUTE

Dagsorden

- Hvorfor lavere fyldning "Low Charge"?
- Hvordan kan I lave anlæggene?
- Hvad skal I passe på med?
- FARS projektet - Hvad har vi målt os frem til.
- Konklusion


DANISH
TECHNOLOGICAL
INSTITUTE
Hvorfor lavere fyldning ”Low Charge”?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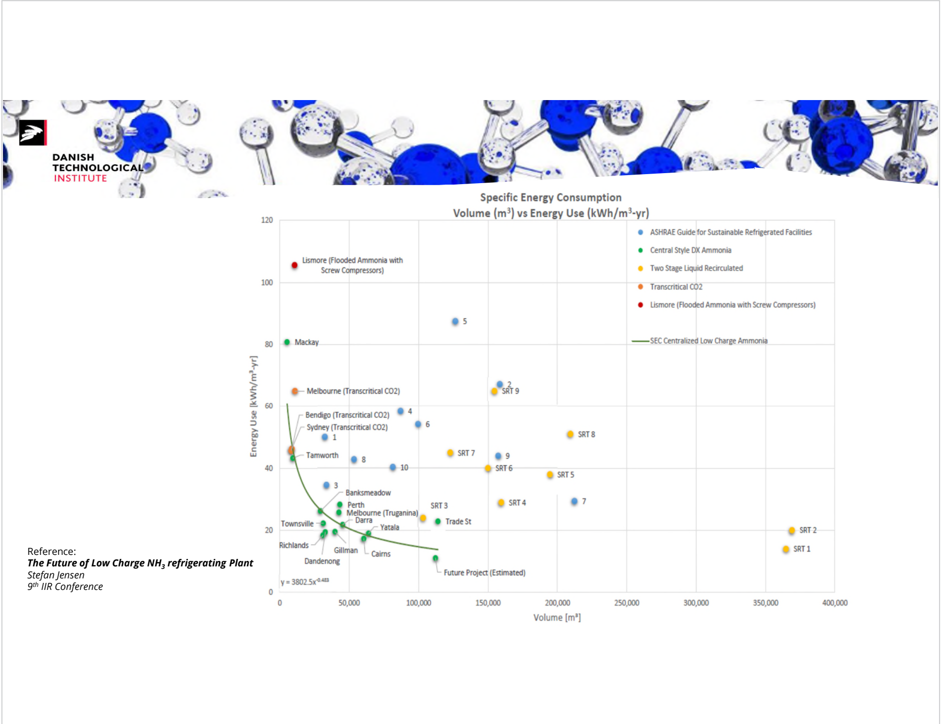
greater than 1500 ppm (ERPG-3)
Maks koncentration i 1 time uden at være livstruende
greater than 150 ppm (ERPG-2)
Maks koncentration i 1 time uden at få alvorlige konsekvenser
greater than 25 ppm (ERPG-1)
Maks koncentration i 1 time hvor konsekvenserne er milde
wind direction confidence lines
SC – 0,1 kg/kW
SC – 2,6 kg/kW
170 kg
4500 kg
to scale
100m
270m
300m
700m
3000m
meters
wind (1,5 m/s)
Kapacitet 1760 kW
Hele fyldningen tømmes på 10 min
Luften 25°C of 50% RH
Urban omgivelser
Reference:
Star refrigeration
Andy Person
GL 2018
STAR REFRIGERATION
In business to secure a better future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Specific Energy Consumption
Volume (m³) vs Energy Use (kWh/m³-yr)
ASHRAE Guide for Sustainable Refrigerated Facilities
Central Style DX Ammonia
Two Stage Liquid Recirculated
Transcritical CO2
Lismore (Flooded Ammonia with Screw Compressors)
SEC Centralized Low Charge Ammonia
Lismore (Flooded Ammonia with Screw Compressors)
Mackay
Melbourne (Transcritical CO2)
Bendigo (Transcritical CO2)
Sydney (Transcritical CO2)
Tamworth
Banksmeadow
Perth
Melbourne (Truganina)
Darra
Townsville
Yatala
Richlands
Gillman
Cairns
Dandenong
Trade St
Future Project (Estimated)
SRT 1
SRT 2
SRT 3
SRT 4
SRT 5
SRT 6
SRT 7
SRT 8
SRT 9
y = 3802.5x^-0.483
Energy Use [kWh/m³-yr]
Volume [m³]
Reference:
The Future of Low Charge NH3 refrigerating Plant
Stefan Jensen
9th IIR Conference


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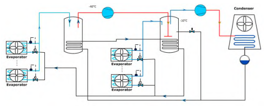
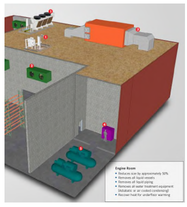
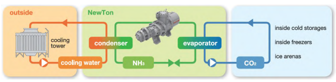
Hvordan kan I lave anlæggene?

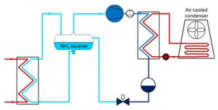
Hvad findes der af anlægstyper?

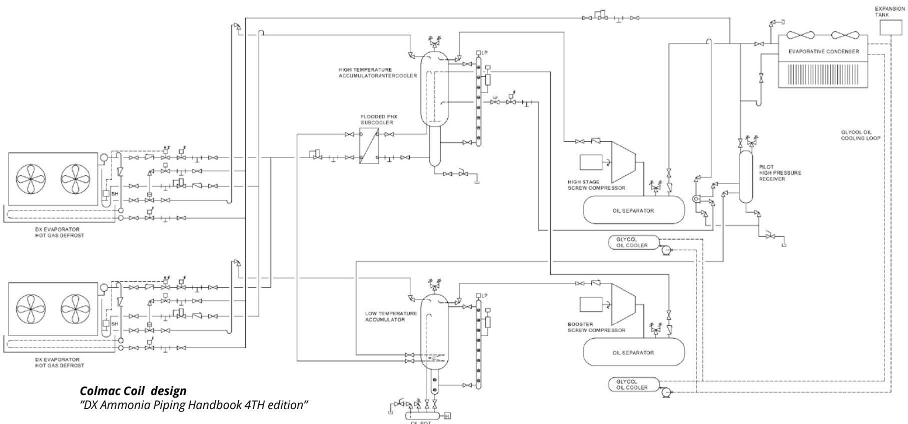
- Centraliserede systemer
  - Ren ammoniak
    - Scantec, Colmac Coil, Frick, Star
  - Kaskade systemer (ammoniak/CO_2)
    - Mayekawa, M&M, Johnson Controls
  - Indirekte systemer (ammoniak/brine)
- Lokaliserede systemer
  - Evapco, NXTCOLD











Colmac Coil design
"DX Ammonia Piping Handbook 4TH edition"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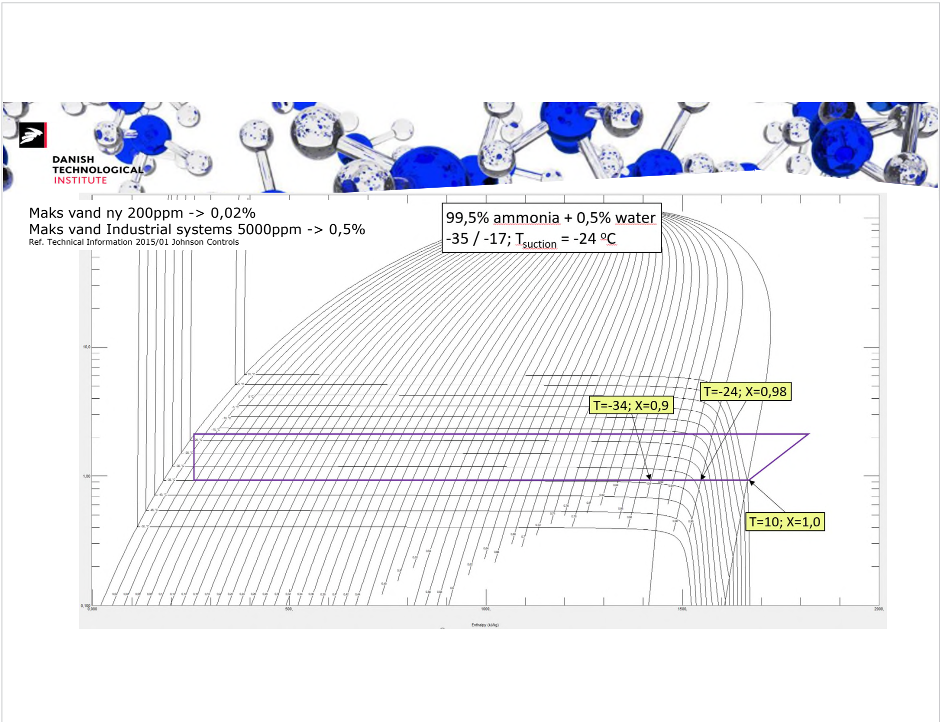
Hvad skal I passe på med?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Maks vand ny 200ppm -> 0,02%
Maks vand Industrial systems 5000ppm -> 0,5%
Ref. Technical Information 2015/01 Johnson Controls
99,5% ammonia + 0,5% water
-35 / -17; T_suction = -24 ºC
T=-34; X=0,9
T=-24; X=0,98
T=10; X=1,0

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FARS projektet – Hvad vi har målt os frem til

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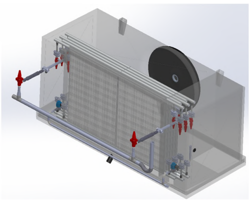
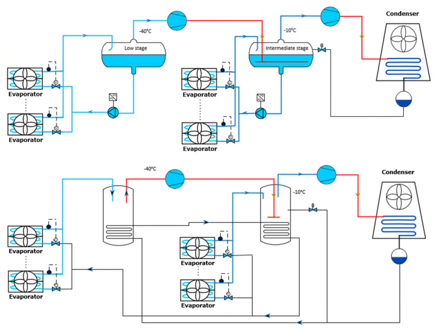
Hvad er der kigget på i projektet?

- CCR løsning
- WDX løsning
- Microchannel fordamper





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Laboratorie test opstilling

Tube arrangement	Inline		Refrigerant	R717	
Tube columns	8		Capacity	24,6	kW
Tube rows	18		Evaporation temperature	-30	°C
Number of circuits	6		Feed rate pump	1,2	
Tube length	1360	mm	Air flow	15146	m³/h
Pipe outer diameter	15,6	mm	Air face velocity	3,5	m/s
Pipe inner diameter	14,6	mm	Air inlet temperature	-20	°C
Tube spacing	50x50	mm	Air inlet humidity	95	%
Fin spacing	12	mm	Air outlet temperature	-23,7	°C
Fin thickness	0,5	mm	Air outlet humidity	100	%
Pipe material	AISI 304		Sensible heat rate	90,3	%
Fin material	Aluminium				
Surface area	84,7	m²			

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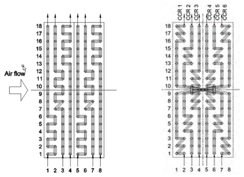
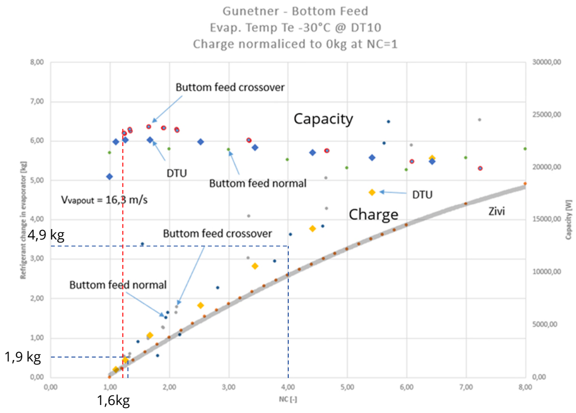
CCR tests



Reduktion i fyldning fra NC 4 og ned til 1,2 =
1,9 kg / 4,9 kg = 39%



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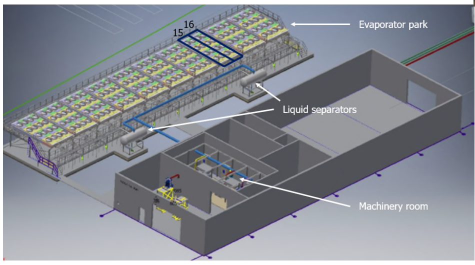
Field test



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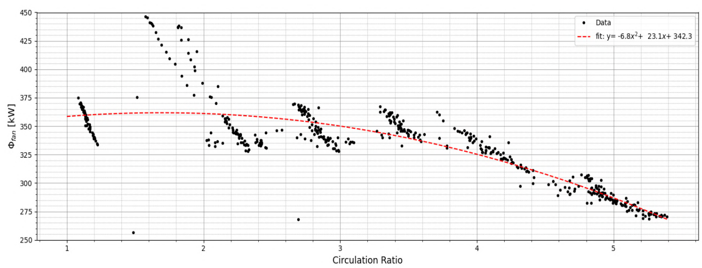
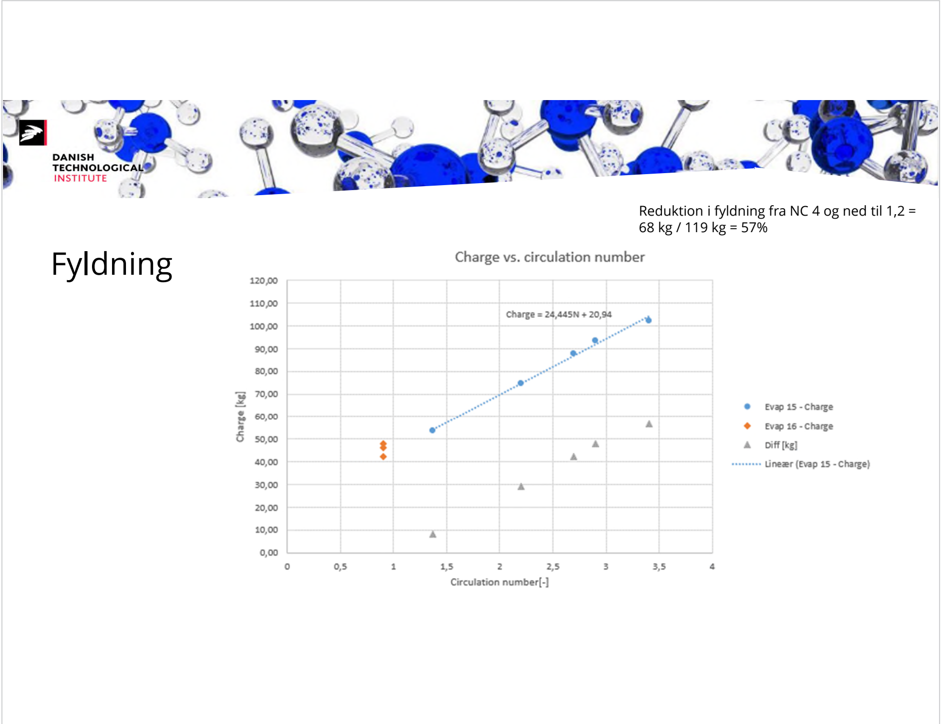
Kapacitet

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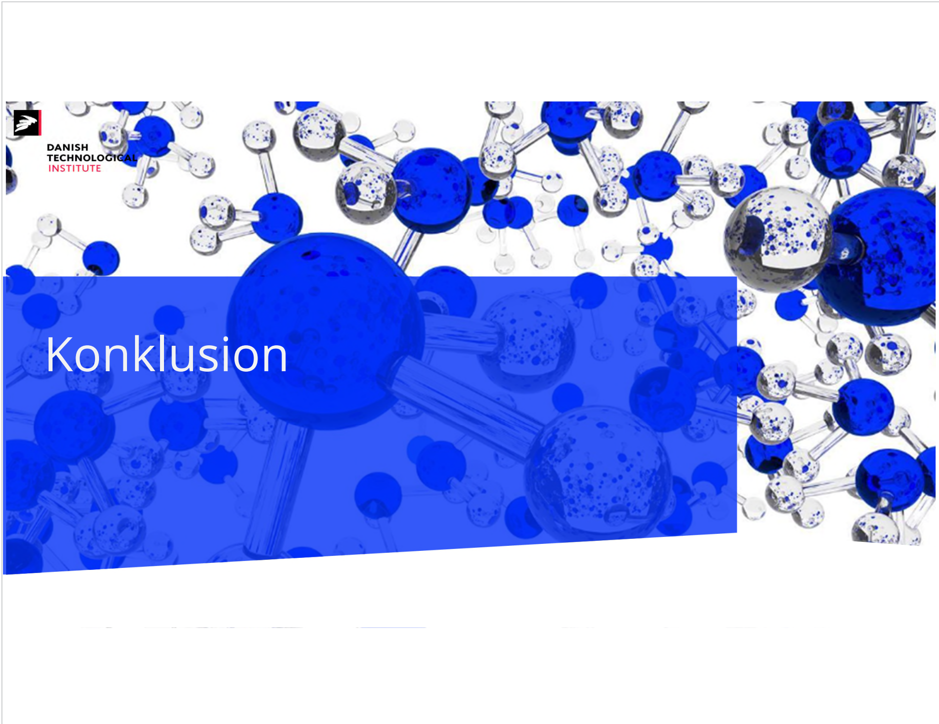
Reduktion i fyldning fra NC 4 og ned til 1,2 =
68 kg / 119 kg = 57%
Fyldning
Charge vs. circulation number
Charge = 24,445N + 20,94
Charge [kg]
Circulation number[-]
Evap 15 - Charge
Evap 16 - Charge
Diff [kg]
Lineær (Evap 15 - Charge)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Konklusion

Konklusion

- "Low Charge Ammonia" anlæg kan laves i dag
- Noget tyder på at de er mere energieffektiv en traditionel anlæg
- Vigtigt at holde vand, olie og luft ud af systemerne
- Med "state-of-the-art" fordampere kan man komme ned til NC på 1.2
- Omkring 40% lavere fyldning i laboratorie test og 57% i "field test"
- Field test giver lovende resultater

"Low Charge Ammonia" er en rigtig god ide


Uddannelse og anvendelse af kommercielle og industrielle trans-kritiske CO2 anlæg
Frits Giversen, lektor Aarhus Maskinmesterskole
Per Skærbæk Nielsen, Cool Partners
Aarhus Maskinmesterskole


Agenda
1. Hvordan er CO2 anlæg blevet interessant for Maskinmester professionen?
2. Uddannelse vs. Forskning og Udvikling (FoU)!
3. Samarbejde med erhvervslivet
4. Konkret udviklingsprojekt i samarbejde med Cool Partners
2
Aarhus Maskinmesterskole

Hvordan er CO2 køleanlæg blevet interessant?

2 grundsten i professionsuddannelserne.

For Maskinmesterprofessionen gælder:

Uddannelsen er reguleret af:

- BEK nr. 1348 af 23/11/2018, Bekendtgørelse om uddannelsen til maskinmester

Forskning og Udvikling (FoU):

- BEK nr. 1459 af 24. juni 2021, Bekendtgørelse om stillingsstruktur for undervisere ved erhvervsakademiuddannelser og professionsbacheloruddannelser ved maritime uddannelsesinstitutioner.

3 Aarhus Maskinmesterskole

Hvad står der så i Bek nr. 1348 og 1459?

-at det de studerende kommer op i, skal stemme overens med det de kommer ud i!

-og

-at det der forskes og udvikles i, er det erhvervslivet har gang i!

4 Aarhus Maskinmesterskole

CO2 anlægget på AAMS

Kølekreds: 10 kw køl og 25 kw frost

Køleeffekt ved fordampning -10°C

Frosteffekt ved fordampning -50°C

Kølerum, køleinstallation 7 kw

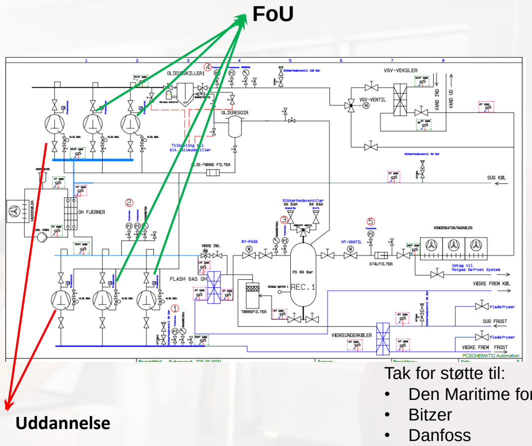
Frostrum, frostinstallation 4 kw

3 stk. Bitzer transkritiske kølekompressorer Max driftstryk: 160 bar (100 bar på sugesiden

3 stk. Bitzer subkritiske frostkompressorer Max driftstryk: 100 bar (100 bar på sugesiden)

Styring: Danfoss AK-SM 350

Gaskøler kapacitet: 75 kW



Tak for støtte til:
- Den Maritime fond
- Bitzer
- Danfoss
- HB products

5 Aarhus Maskinmesterskole

Uddannelse og efteruddannelse

Anlægget bruges til uddannelse inden for køl med fokus på:

- Generel kendskab til CO2 køl og varmepumpe teori samt teknik omsættes til praksis
- Styring og indkøring af 2-trins anlæg i relation til kundebehov
- Fejlfinding og vedligehold på C02 anlæg

6 Aarhus Maskinmesterskole

Forskning og Udvikling; CO2 Fase 2

Få eftervist at man kan lave CO2 anlæg, med indfrysning i pladefrysere og hotgas afrimning, i industrielt design!

-altså

Erstatte traditionelle ammoniak anlæg eller CO2/NH3 kaskade anlæg med rene CO2 anlæg

7 Aarhus Maskinmesterskole

Som uddannelsesinstitution tilstræber AAMS at finde eksterne samarbejdspartnere for deltagelse i og medfinansiering af FoU aktiviteter!

Nuværende anlæg er driftsklar og dimensioneret til videreudvikling

Nyt anlæg er "designet", overslagsdimensioneret og budgetteret.

Indledt samarbejde med øvrige Maskinmesterskoler for involvering og kompetenceløft

Ongoing kontakt til relevante samarbejdspartnere for evt. støtte/sponsorater og/eller medfinansiering af "hardware" delen;

- Pumpeseperator
- Pladefryser (CARSOE/Freezertech deltager på denne del)
- Olieafkoger
- Olieudskiller
- Varmgas afrimning mv.
- Styringere

8 Aarhus Maskinmesterskole

CO2 transcritical system at AAMS

Capacity:

10 kW cooling ET -10°C

25 kW freezing ET -50°C

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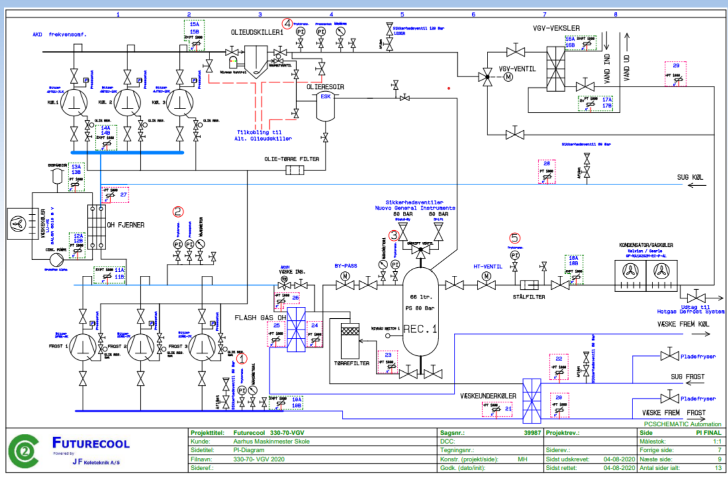
Module 2

CO2 transcritical system on AAMS



Build as a commercial system but capeable of running -50 °C

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Polar Princess with CO2 / NH3
- 50 °C / + 27 °C

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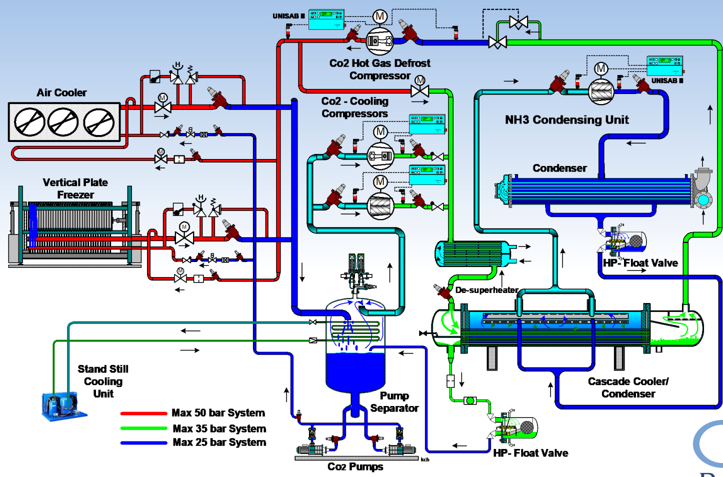
CO2 / NH3 cascade system



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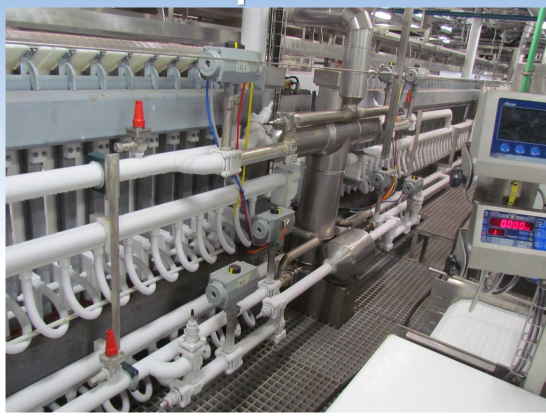
16 vertical plate freezers



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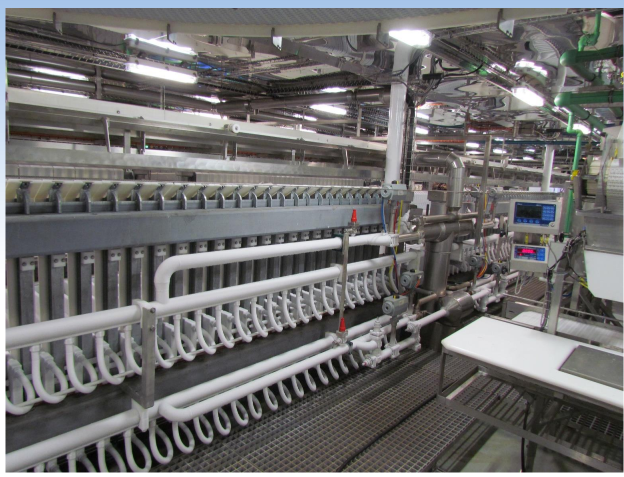
With hot gas defrost



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5 horizontal plate freezers

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CO2 pump separator

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CO2/ NH3 very compact machine room

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Big CO2 / NH3 Cascade Cooler

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Very compact machine room

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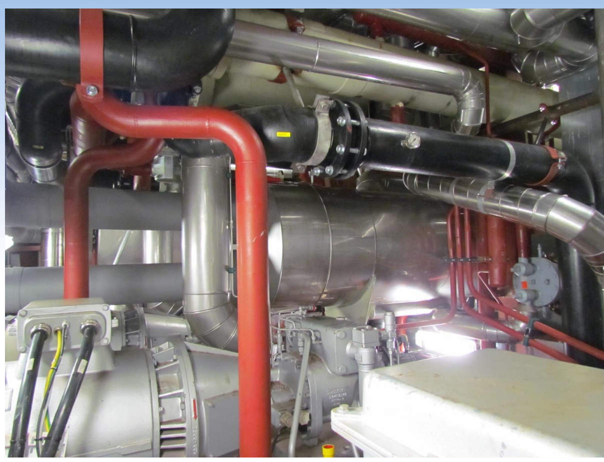
Very limited space for service



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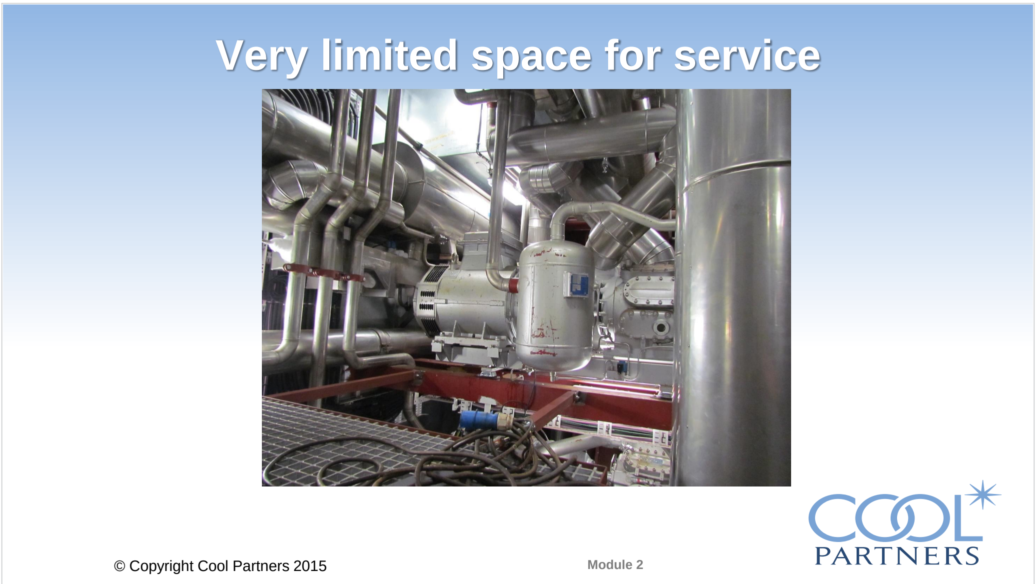
Very limited space for service
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CO2 HPC recip compressors
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Servicing machines is very difficult

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CO2 / NH3 leak risks?

When NH3 mixes with CO2 it creates ammoniumcarbamate.

Difficult to clean out of refrigeration systems

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24

Module 1

CO2 transcritical flooded industrial production systems?

Sure, it can be done
Three problems needs to be addressed and solved:

1) Transcritical CO2 compressors using normal commercial oil separators have oil out blow of 0,1 % to 2 % (1000 – 20000 ppm)

2) Oil rectifiers where no liquid can be feed to LP compressor suction lines?
(Same problem for CO2 / NH3 and CO2 transcritical systems)

3) Hot gas defrost where approx. 1200 kW hot gas capacity should be available instantly?
(Efficient defrost of vertical plate freezers)

25

Module 1

COOL PARTNERS

Oil return CO2 flooded systems?

Example:

Mass flow from compressor: 2.5 kg/s

Oil content in CO2 gas: 0.1 %

Oil flow is: 2.5 x 0.1/100 = 0.0025 kg/s

0.0025 kg/s is the amount of oil we must remove from pump separator to keep oil content in equilibrium.

So, min. 10 % of compressor mass flow must be evaporated in oil rectifier just to keep oil in equilibrium in pump separator.

26

Module 1

COOL PARTNERS

Oil return in Flooded CO2 systems

We can also find the percentage we must evaporate in oil rectifier the as the relation between oil content in discharge gas and the max. acceptable content in pump separator.

If we want max. 1 % oil out blow is 0.1 % (recommended on R22)
0.1% / 1% = 0.001 / 0.01 = **10 %**

Might result in very big oil rectifier.

Heat to oil rectifier is taken from subcooling of liquid to separator.
The heat available is limited.

27

Module 1

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CO2 flooded transcritical solutions

Only solution to oil problems in transcritical CO2 flooded systems:

Very efficient oil separators with oil out blow less than 300 ppm (expensive).

Safe oil rectifier systems (no liquid in suction lines)

Solution for hot gas defrost:

Hot gas defrost system with “gas / liquid” reserve for efficient defrost.

Using gas cooler / condenser for hot gas production during defrost

28

Module 1

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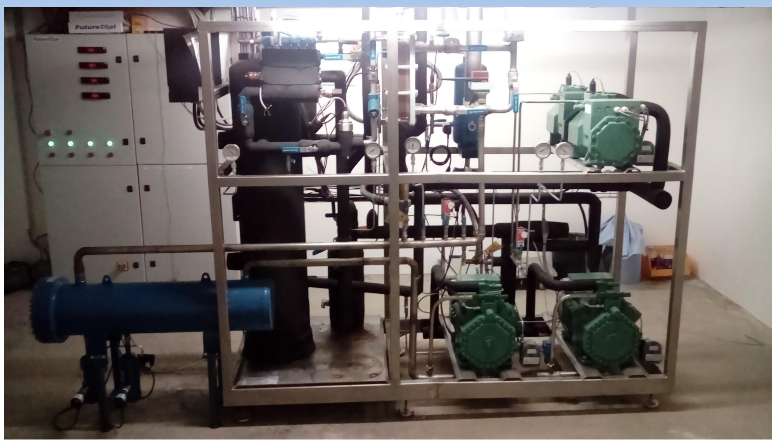
Test system in a supermarked



Topped up with approx 8 litres oil after start up to be in balance

Module 2

COOL PARTNERS

Test system in a supermarked

After mounting special designed oil separator: Approx 7,5 liters of oil drained.

Oil out blow low.

Oil out blow not meassured. (Needs to be clarified)

Module 2

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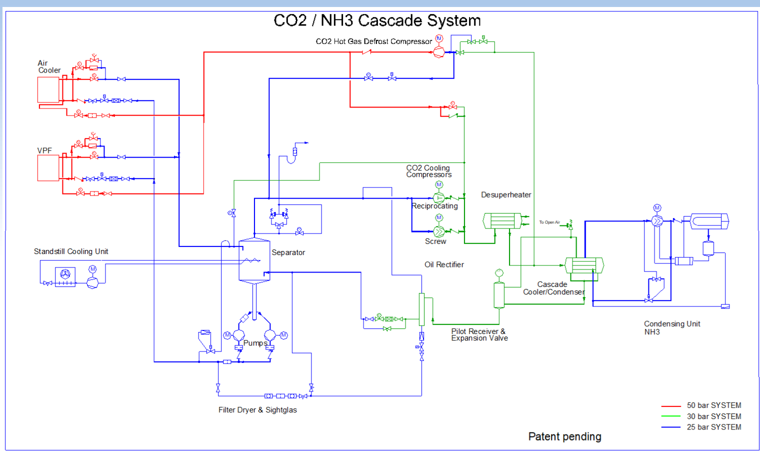
CO2 / NH3 Cascade system concept



Module 2

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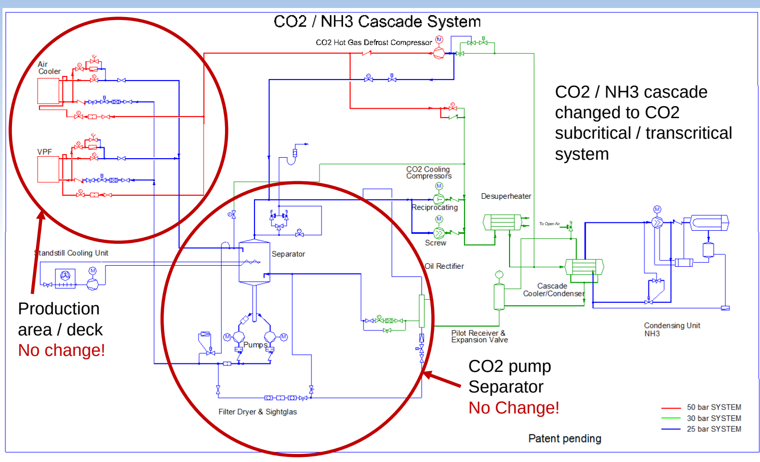
Industrial CO2 trancritical production consept



Condensing ≤ 30 °C
Subcritical

Condensing / gas cooling ≥ 30 °C
Transcritical
(Approx 25% less capacity)

Module 2

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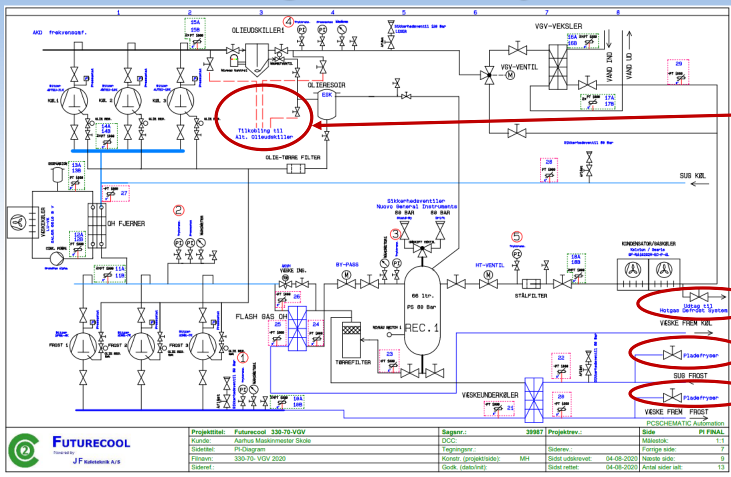
PI Diagram CO2 system AAMS



Module 2

What are needed for fase two?

- A special made highly efficient oil separator (oil out blow ≤ 300 ppm)
- Pump separator with CO2 pump and control system
- Special vessel and control system for high-capacity hot gas defrost system
- Vertical plate freezer with control system
- Pipes, fittings, valves, engineering and assembly

Module 2

Objectives for fase two.

Demonstrate CO2 transcritical systems can handle flooded production systems efficiently

Show a solution for small, mittle sized and large fishing vessels

Develop a concept for industrial transcritical CO2 flooded systems which can be used in all industrial applications

Train refrigeration and machinery engineers in commercial and industrial transcritical CO2 systems

Module 2

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Air and Water contamination of NH3 refrigeration and heat pump systems

Per Skærbæk Nielsen
Cool Partners

1 • Module 1

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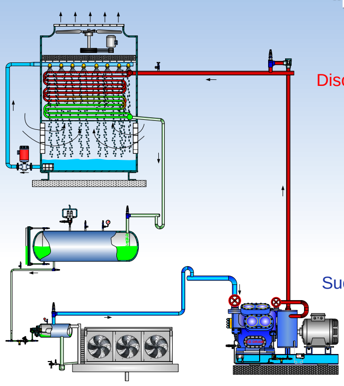
Consequences on performance

"Rules of thumb"



Discharge pressure

Suction pressure

1°C increase mean approx.:
1% lower cooling capacity
3% lower COP
3.1% higher power consumption

Air will raise discharge pressure

1°C decrease mean approx.:

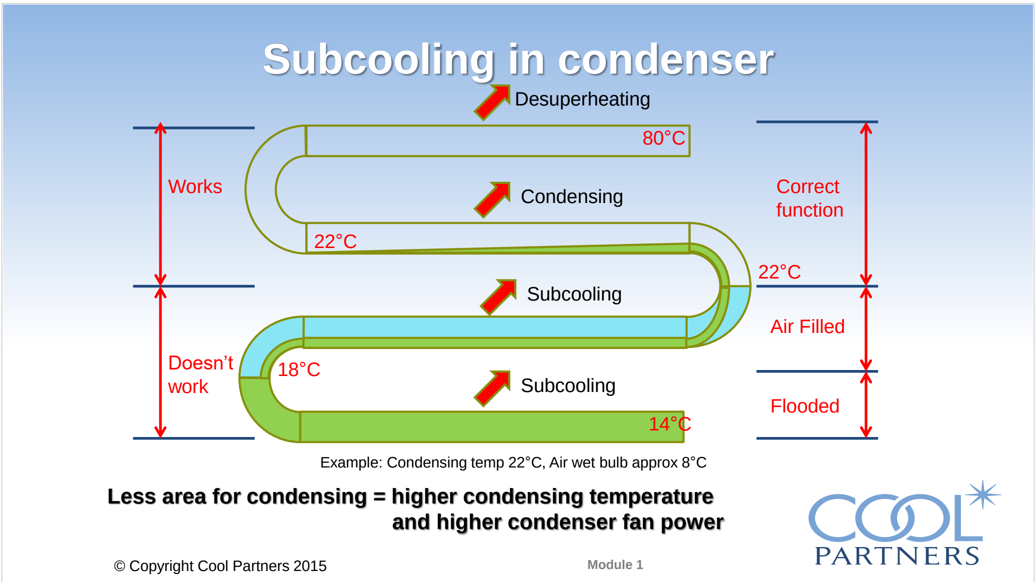
At	Capacity	COP	Power
+10°C	-3.6%	-5.0%	+5.2%
0°C	-4.0%	-4.3%	+4.5%
-10°C	-4.4%	-3.8%	+4.0%
-20°C	-5.1%	-3.5%	+3.6%
-30°C	-5.5%	-3.9%	+4.1%
-40°C	-6.5%	-4.4%	+4.6%
-50°C	-7.3%	-5.0%	+5.2%

H2O will lower suction pressure

Numbers from average of Sabroe recip and screw
Power is with unchanged cooling capacity

 Module 1

COOL PARTNERS


Subcooling in condenser
Desuperheating
80°C
Works
Condensing
Correct
function
22°C
22°C
Subcooling
Air Filled
Doesn't
work
18°C
Subcooling
Flooded
14°C
Example: Condensing temp 22°C, Air wet bulb approx 8°C
Less area for condensing = higher condensing temperature
and higher condenser fan power
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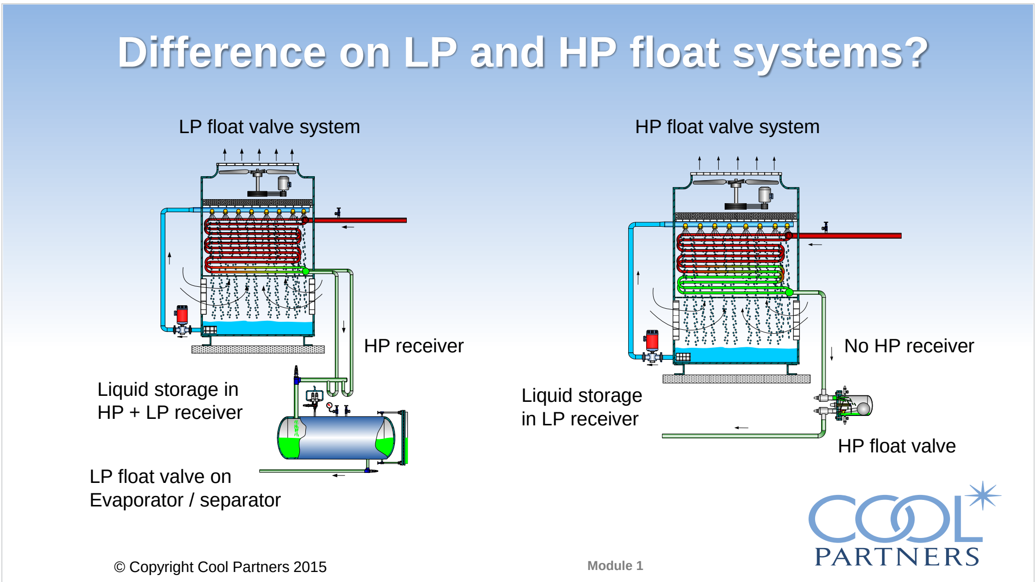
Module 1
COOL PARTNERS


Difference on LP and HP float systems?
LP float valve system
HP float valve system
HP receiver
No HP receiver
Liquid storage in
HP + LP receiver
Liquid storage
in LP receiver
HP float valve
LP float valve on
Evaporator / separator
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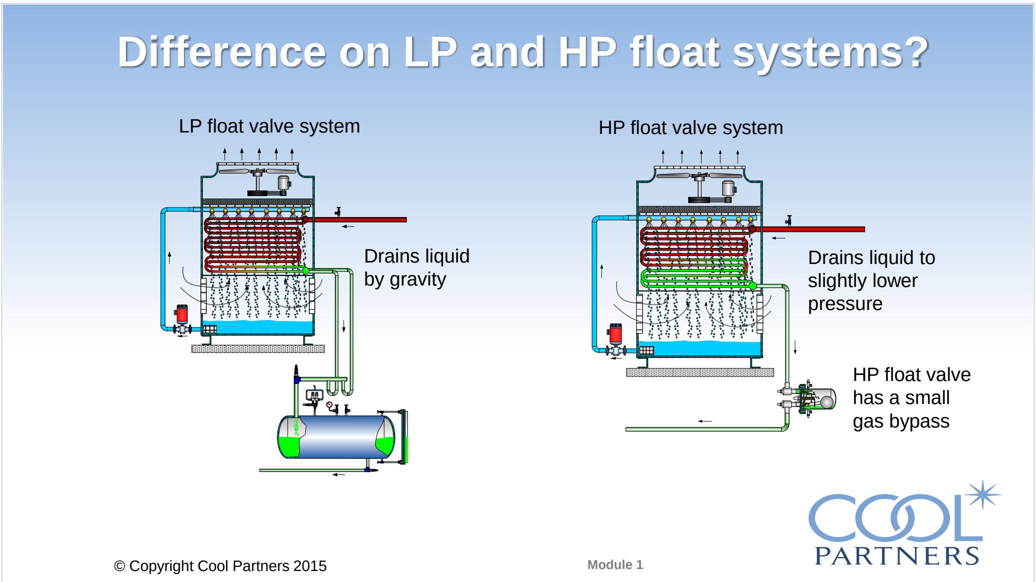
Module 1
COOL PARTNERS


Difference on LP and HP float systems?
LP float valve system
Drains liquid by gravity
HP float valve system
Drains liquid to slightly lower pressure
HP float valve has a small gas bypass
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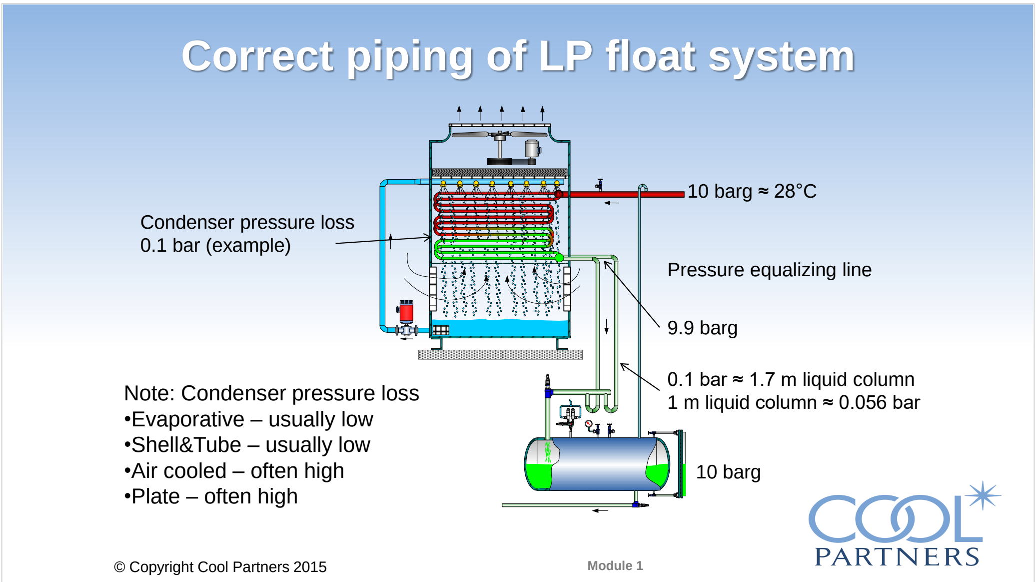
Module 1


Correct piping of LP float system
Condenser pressure loss 0.1 bar (example)
10 barg ≈ 28°C
Pressure equalizing line
9.9 barg
0.1 bar ≈ 1.7 m liquid column
1 m liquid column ≈ 0.056 bar
10 barg
Note: Condenser pressure loss
•Evaporative – usually low
•Shell&Tube – usually low
•Air cooled – often high
•Plate – often high
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Calculation tools?

Cool Partners have developed a calculation tool for free download.

CPAW Calc. v1.6 download from this link:
https://www.dropbox.com/sh/mhn3gl9j7i6efqe/AABOoP9GnQJI8WjHJcT8KCaaa?dl=0

The program will calculate the influence of air and water on a one stage system like:

- Loss in system capacity
- Increased power consumption
- Loss in system efficiency
- Pay back time for water and air purgers if cost and Euro/kWh is known

7 Module 1

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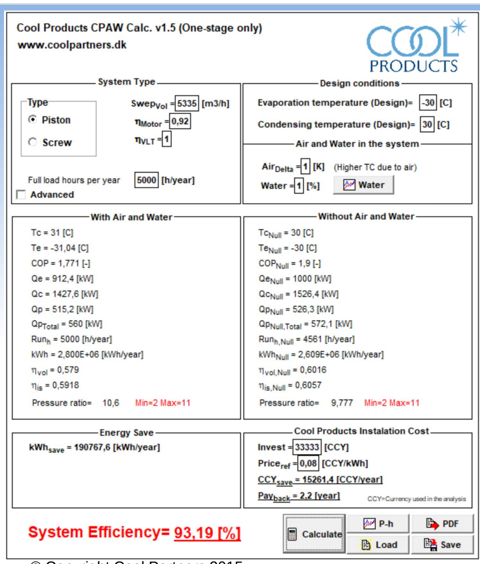

-30 °C EP / 30 °C CP

1 % H2O in evaporator

1 °C higher cond. temp. due to air

Technical clean NH3 has max. 0,3 % H2O

All H2O concentrates in the evaporator

If half the NH3 is on the HP side, the LP side will have 0,6 % H2O

8 Module 1

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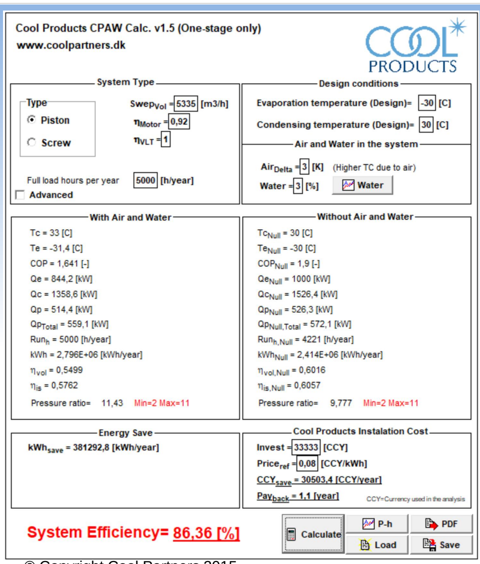
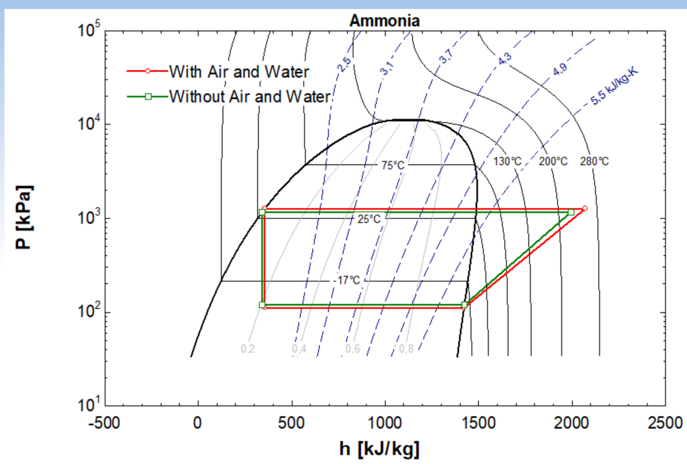


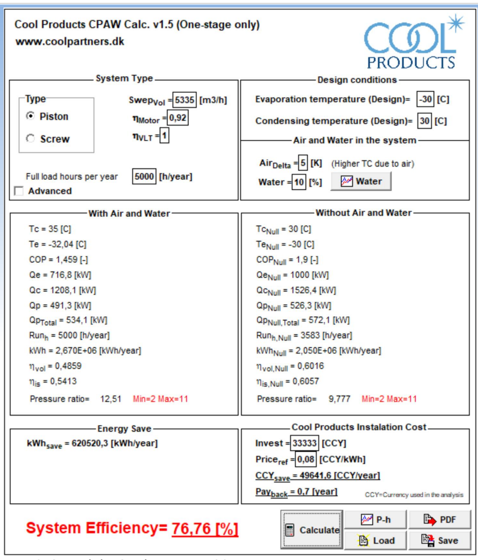
-30 °C EP / 30 °C CP

3 % H2O in evaporator

3 °C higher cond temp due to air

Results in Log PH diagram





-30 °C EP / 30 °C CP

10 % H2O in evaporator

5 °C higher cond temp due to air

11

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What is industrial NH3 heat pumps?

Unfortuately not just an industrial refrigeration system at higher temperatures / pressures

- Focus is on produced heat and is measured very accurate.
- Heat pumps are sold on COP values (efficiency) COP = Q/Ne
- Standards allow for uncertainty of 5 % on power and 5-7 % on capacity on compressors
- Much shorter service intervals on compressors means higher service cost

- Air and water in system can spoil COP and business case!

Module 2

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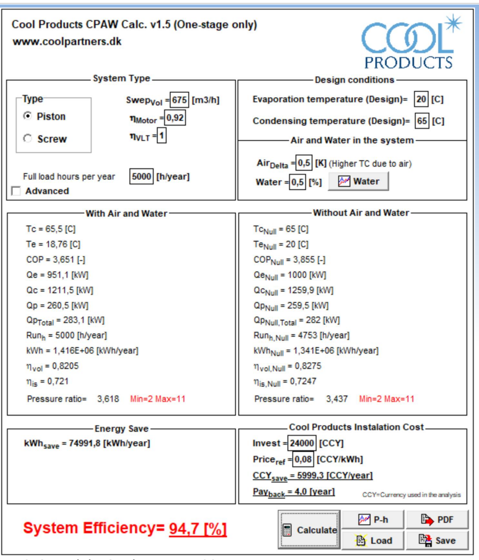

NH3 heat pump running conditions!

20 °EP / 65 °C CP

0,5 % H_2O in evaporator

0,5 °C higher CP due to air

Technical clean NH3 has max. 0,3 % H_2O

All H_2O concentrates in the evaporator

If half the NH3 is on the HP side, the LP side will have 0,6 % H_2O

13

Module 1

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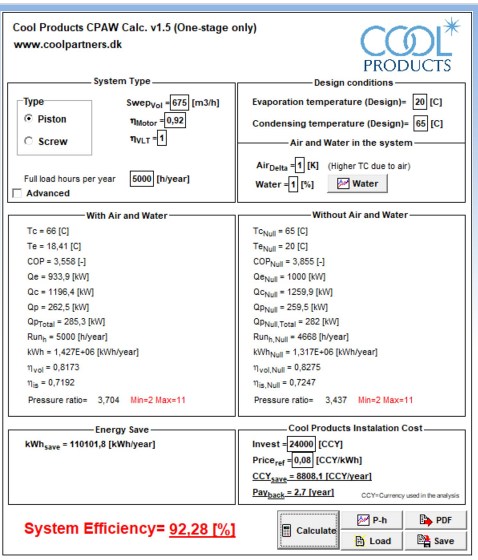

NH3 heat pump running conditions!

20 °EP / 65 °C CP

1 % H_2O in evaporator

1 °C higher CP due to air

14

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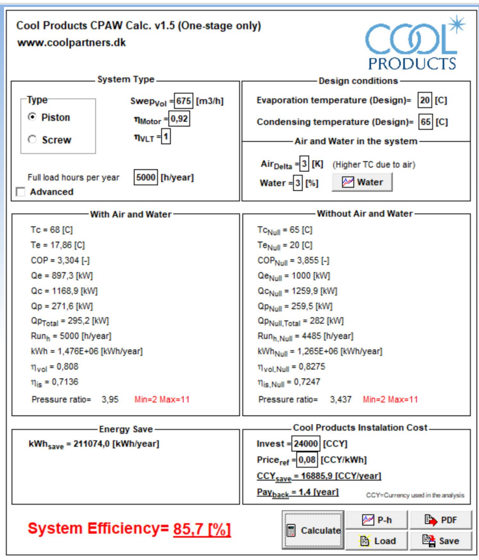

NH3 heat pump running conditions!

20 °EP / 65 °C CP

3 % H2O in evaporator

3 °C higher CP due to air

15

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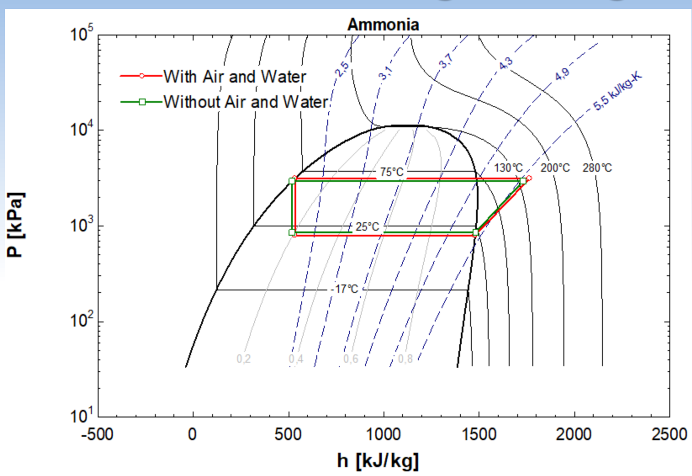
Results in Log PH diagram



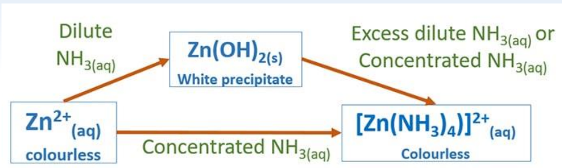
16

Module 1

Zn + NH3 + H2O

Zinc +2 ion and ammonia reaction | Zn^{2+} and NH_3

Aqueous zinc +2 ion solution is **colourless**. When ammonia solution is added to the Zn^{+2} ion, different observations can be seen according to the amount of added ammonia or concentration of ammonia.



17 Module 1

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Zn + NH3 + H2O

Testing:

25% NH3 + H2O + Galvanized washers and bolts

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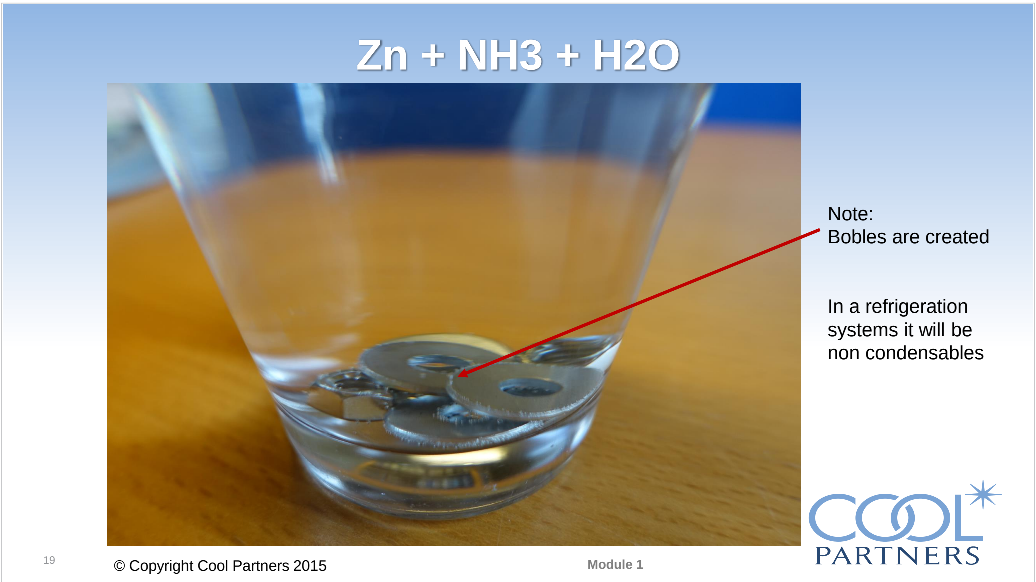
Zn + NH3 + H2O
Note:
Bobles are created
In a refrigeration
systems it will be
non condensables
19
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After 4 days at 21 °C
Zinc is dissollved in
NH3 + H2O
Iron seriously
corroded
20
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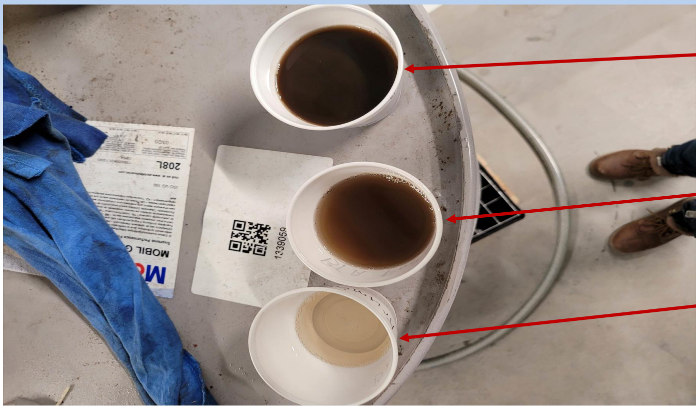
Air (oxygen) + H2O will create chemical reactions in NH3 systems

- When oil decompose in the presence of air (oxygen) it creates organic acids (f.eks. Carboxylic acid)
- NH3 + H2O will emidiately react with the acid and create amides. (Nitrocompounds)
- Amides can have consitancy like thin clay and is a polar chemical substance
- Polar chelmical substances can stick to f.ex. Stainless steel surfaces (heat exchangers)
- Amides in the oil can increase viscosity on the oil and might clogg oil filters
- Chemical reactions accelerate in NH3 system with higher temp. and press.

Module 2

Oil samples from NH3 reciprocating heat pump compressor



Oil from oil filter

Oil from lubrication system after oil pump / filter

Oil from crankcase

Module 2

Why is the oil black?

PAO oils turns black by oxidation or thermal degration (very high temperatures)

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Module 2

Oxydation or very high temperatures?

Oxygen in a NH3 system (air)?

Very high temperatures in oil with NH3?

Or both?

How can this happen?

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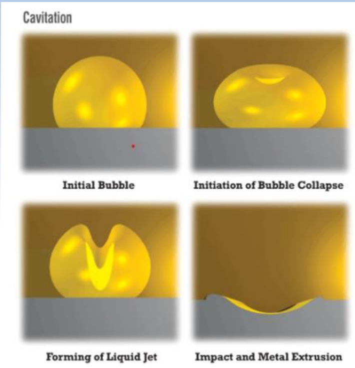
Module 2

Dieseling effect?



In hydraulig systems temperatures up to 1093 °C (2000 °F) can be reached with collapsing air bobbles

In compressor oil systems what temperaures can be reached in collapsing boubbles with NH_3 or NH_3+air?

We might reach temperatures which decompose the oil and / or create chemical reactions.

If air (oxygen) is present oil might decompose and create organic acids (carboxylic acid)

Acid reacts imidately with NH_3 + H_2O and create amides (Nitrocompounds)

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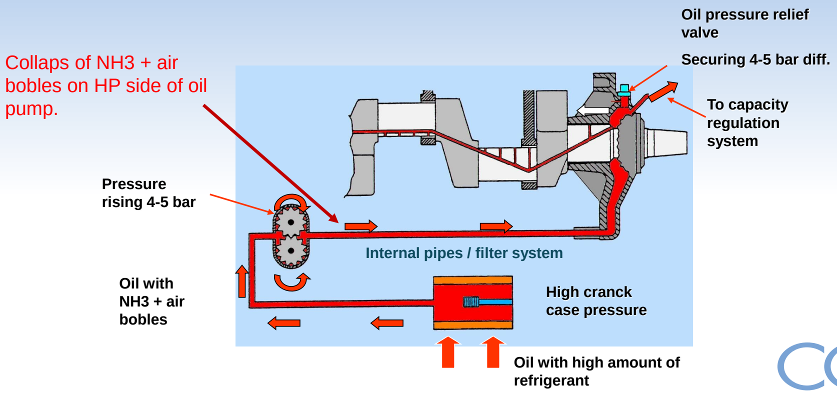
Possible dieseling effect in heat pumps?

Example reciprocating compressor



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 Module 2

Oil from NH3 heat pump Screw compressor with oil pump

Module 2

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Screw compressor oil separator filter

Unknown chemical activity.

Reason unknown but large amounts of air found in system

Module 2

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Oil separator filter
Top and bottom plates galvanized?
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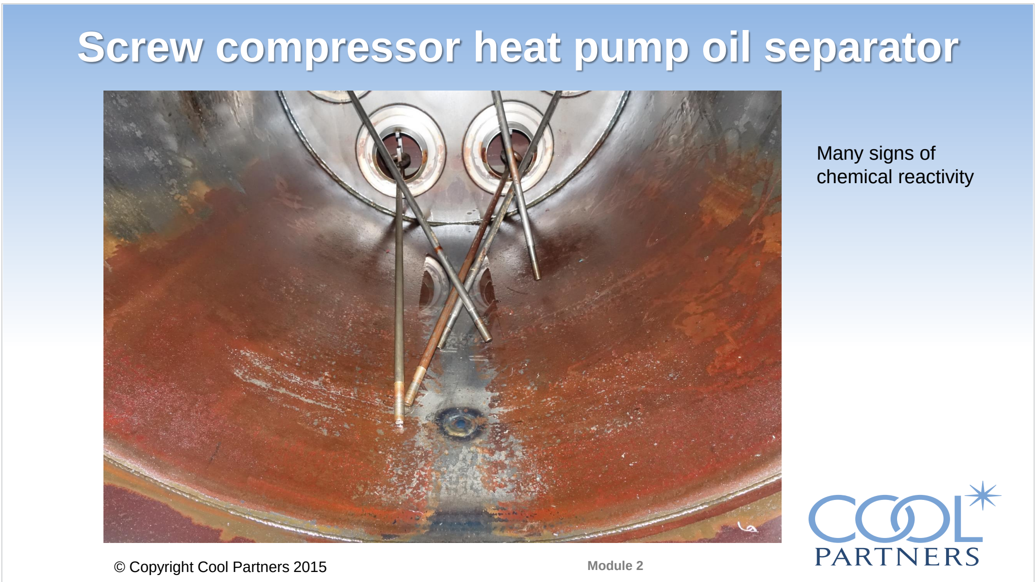
Screw compressor heat pump oil separator
Many signs of chemical reactivity
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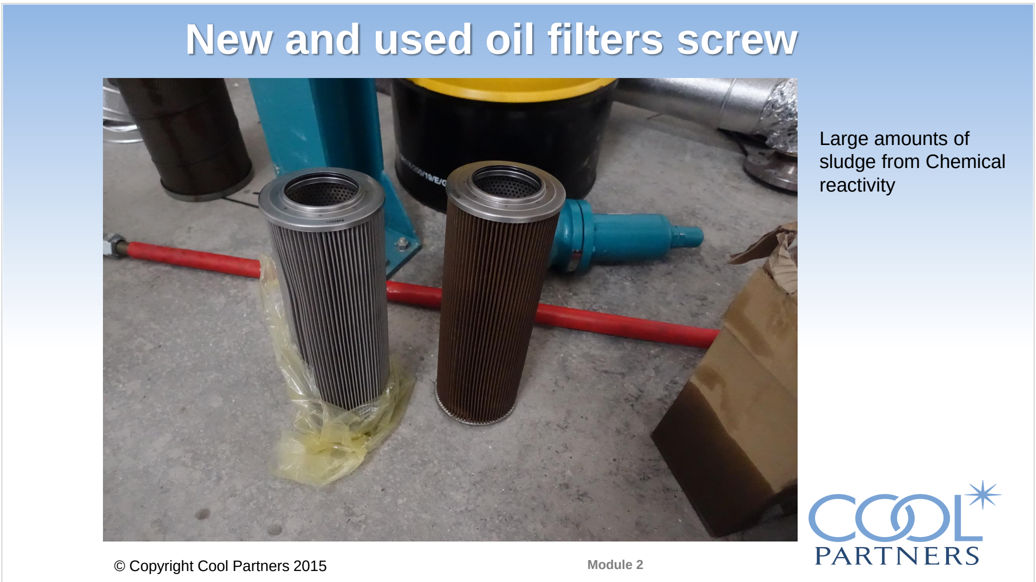
New and used oil filters screw
Large amounts of sludge from Chemical reactivity
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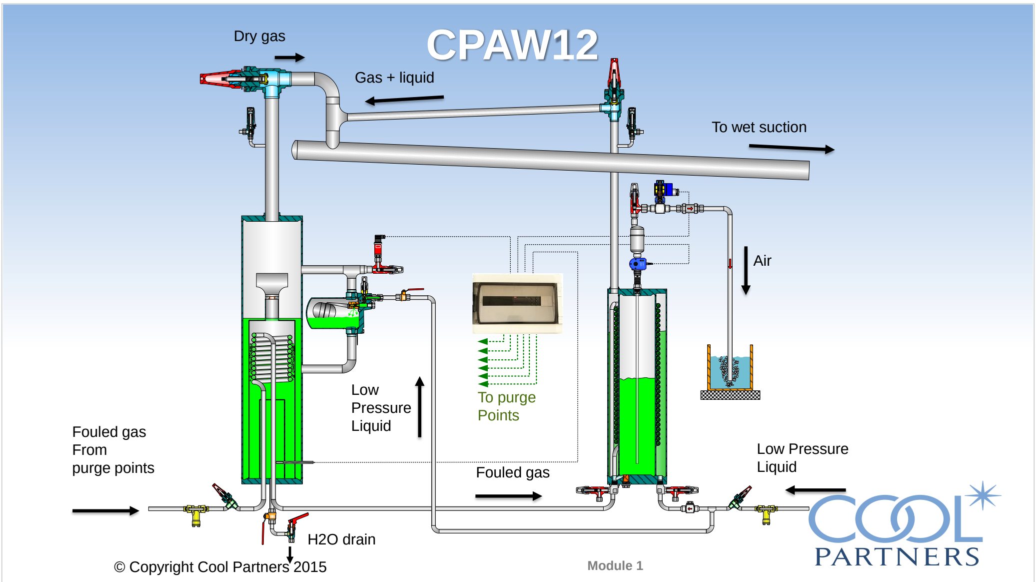
CPAW12
Dry gas
Gas + liquid
To wet suction
Air
Low Pressure Liquid
To purge Points
Fouled gas From purge points
Fouled gas
Low Pressure Liquid
H2O drain
COOL PARTNERS
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Module 1

CPAW12 test

Test of new CPAW12 system af Claus Sørensen Coold Stores

33 Module 1

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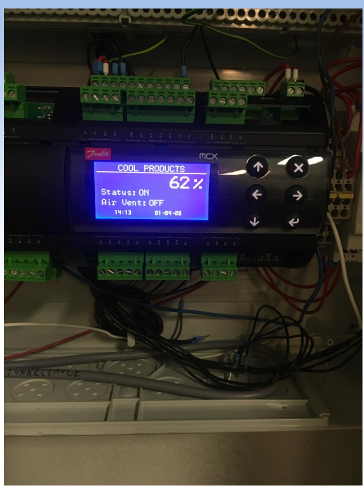
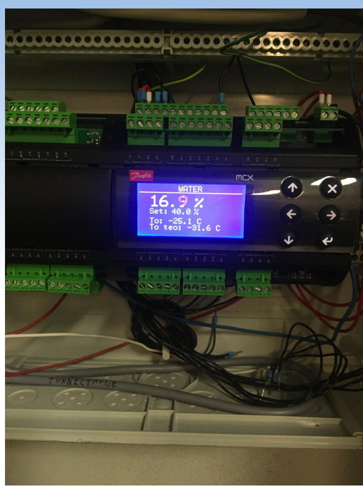
CPAW12 test





Controller showing liquid level in CPA12 and H2O concentration in CPW12

At 40 % H2O gives signal to pump down

At +12 °C gives alarm signal for draining H2O

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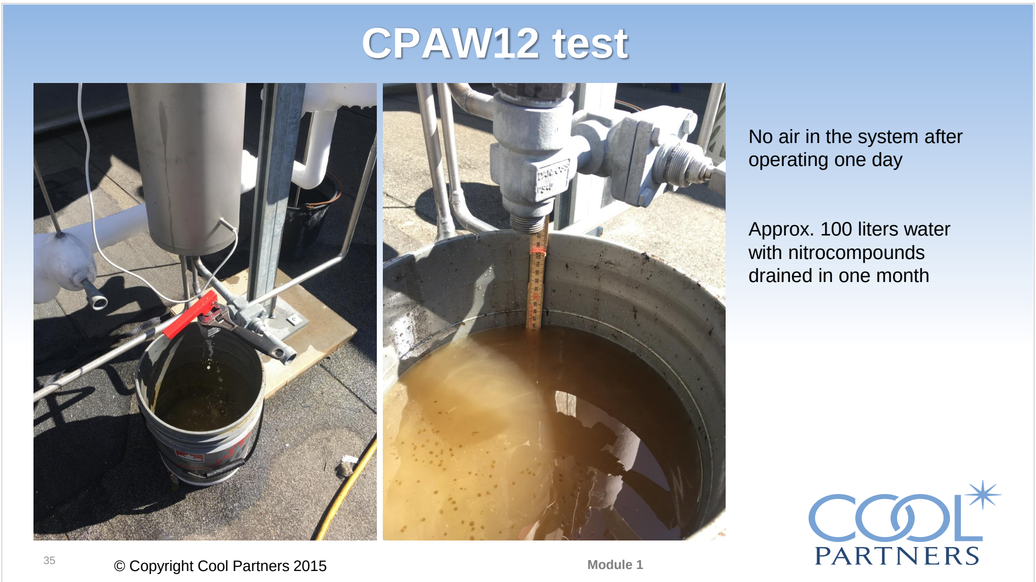
CPAW12 test
No air in the system after operating one day
Approx. 100 liters water with nitrocompounds drained in one month
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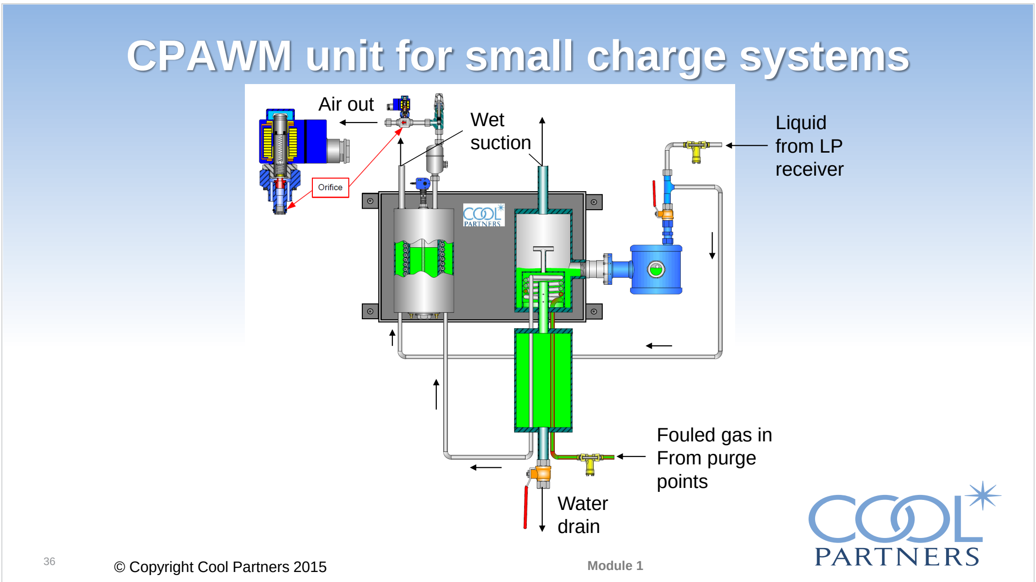
CPAWM unit for small charge systems
Air out
Orifice
Wet suction
Liquid from LP receiver
Fouled gas in From purge points
Water drain
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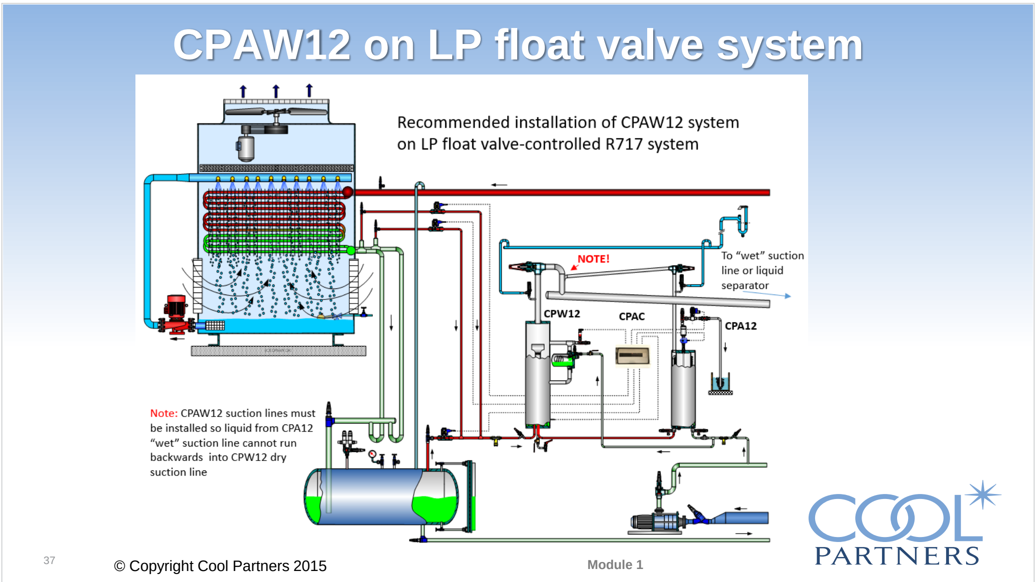
CPAW12 on LP float valve system
Recommended installation of CPAW12 system
on LP float valve-controlled R717 system
NOTE!
To “wet” suction
line or liquid
separator
CPW12
CPAC
CPA12
Note: CPAW12 suction lines must
be installed so liquid from CPA12
“wet” suction line cannot run
backwards into CPW12 dry
suction line
37
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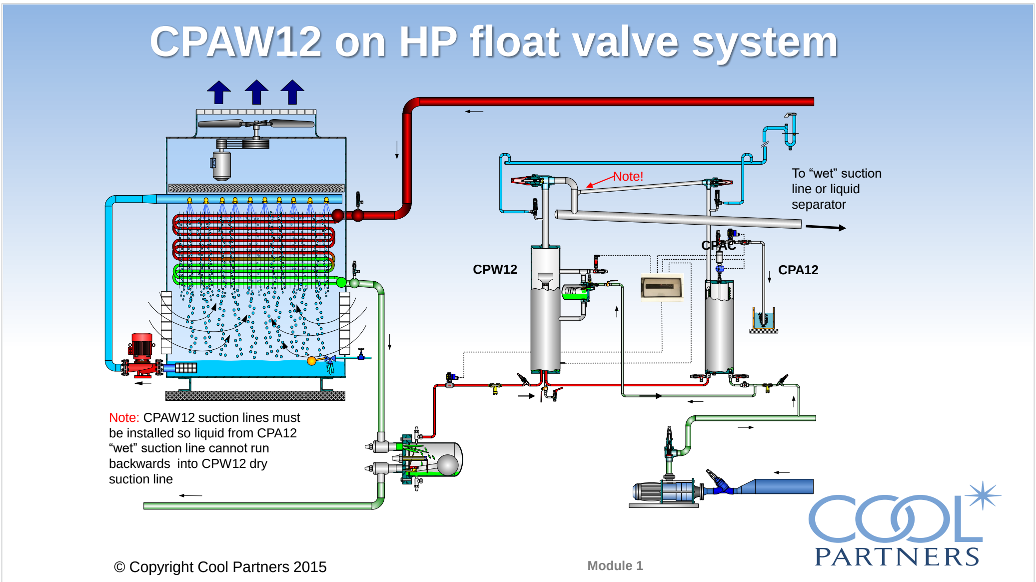
CPAW12 on HP float valve system
Note!
To “wet” suction
line or liquid
separator
CPAC
CPW12
CPA12
Note: CPAW12 suction lines must
be installed so liquid from CPA12
“wet” suction line cannot run
backwards into CPW12 dry
suction line
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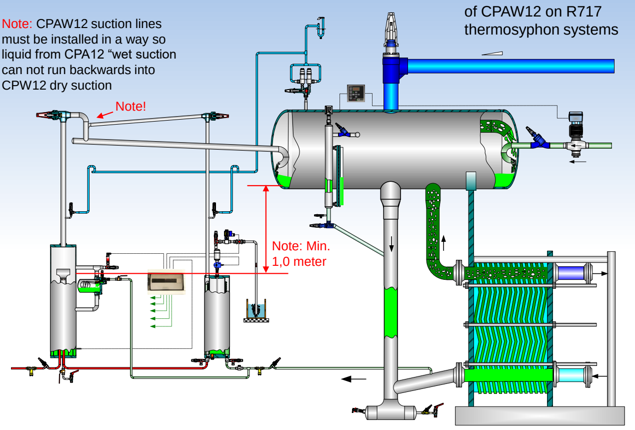
CPAW12 on self circulation systems



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Thank you very much
For your attention

Per Skærbæk Nielsen
Cool Partners

40

- Module 1

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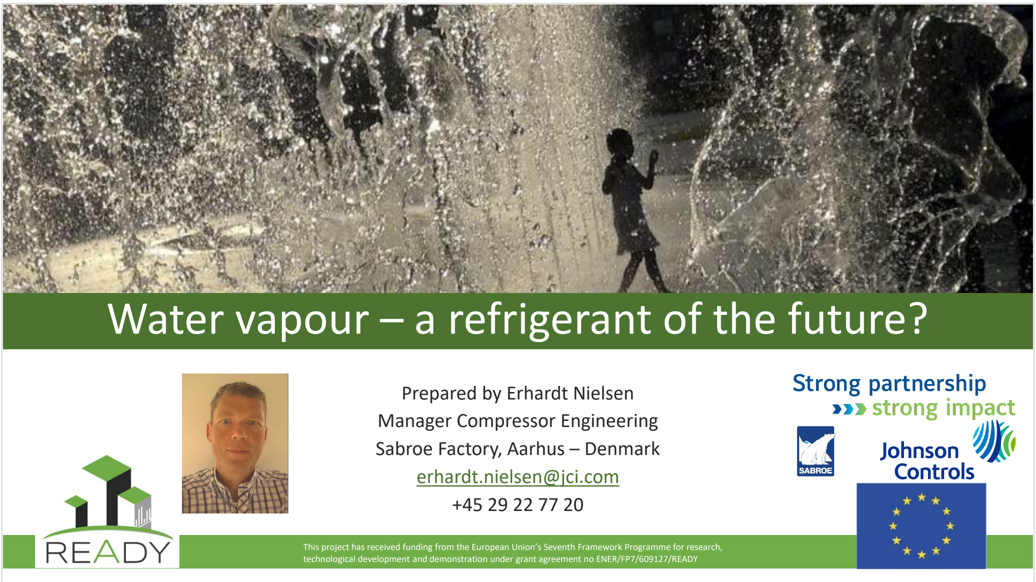

Water vapour – a refrigerant of the future?
Prepared by Erhardt Nielsen
Manager Compressor Engineering
Sabroe Factory, Aarhus – Denmark
erhardt.nielsen@jci.com
+45 29 22 77 20
Strong partnership
strong impact
SABROE
Johnson Controls
READY
This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement no ENER/FP7/609127/READY

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ENERGY STORAGE
RETAIL SYSTEMS
TOTAL BUILDING MANAGEMENT SYSTEMS
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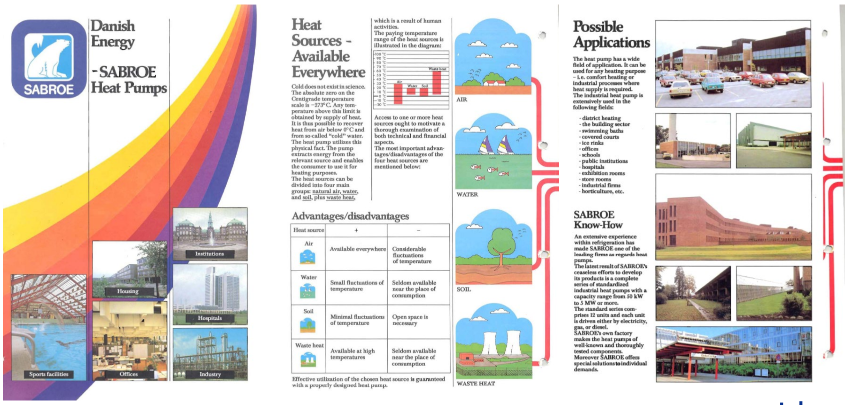
Large scale heat pumps

Brochure from 1982. The key benefits haven't changed, but its now more attractive than ever before….



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Have you heard about Project DRAWDOWN?

* Gigatons CO2 Equivalent Reduced / Sequestered (2020–2050)

SOLUTION	SECTOR(S)	SCENARIO 1 *	SCENARIO 2 *
Reduced Food Waste	Food, Agriculture, and Land Use / Land Sinks	87.45	94.56
Health and Education	Health and Education	85.42	85.42
Plant-Rich Diets	Food, Agriculture, and Land Use / Land Sinks	65.01	91.72
Refrigerant Management	Industry / Buildings	57.75	57.75
Tropical Forest Restoration	Land Sinks	54.45	85.14
Onshore Wind Turbines	Electricity	47.21	147.72
Alternative Refrigerants	Industry / Buildings	43.53	50.53
Utility-Scale Solar Photovoltaics	Electricity	42.32	119.13
Improved Clean Cookstoves	Buildings	31.34	72.65
Distributed Solar Photovoltaics	Electricity	27.98	68.64
Silvopasture	Land Sinks	26.58	42.31
Peatland Protection and Rewetting	Food, Agriculture, and Land Use / Land Sinks	26.03	41.93
Tree Plantations (on Degraded Land)	Land Sinks	22.24	35.94
Temperate Forest Restoration	Land Sinks	19.42	27.85
Concentrated Solar Power	Electricity	18.60	23.96

4 Internal use | December 2019 - Prepared by Erhardt Nielsen

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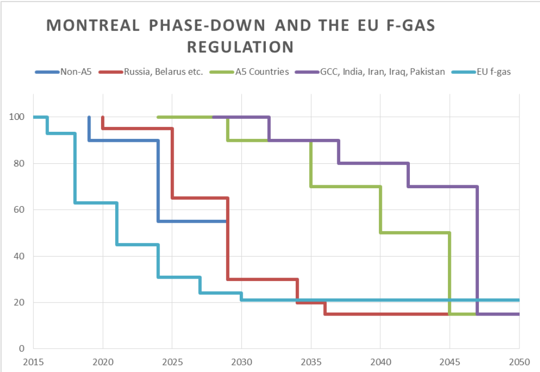
The outcome of the Kigali meeting October 2016



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Water as refrigerant

Advantages

- Water (H_2O or R718) is available globally
- Water is non-flammable, non-toxic and indisputably "green"
- Water is one of the most used secondary refrigerants
- Components for water are available everywhere in the industry.
- Best performance (COP) at high temperatures

Points for consideration

- Freezing point at 0°C. Evaporation only above 0°C*
- Low density; requires high swept volume
- It may be salty and contain other minerals or chemical components
- It may be contaminated with biological substances.

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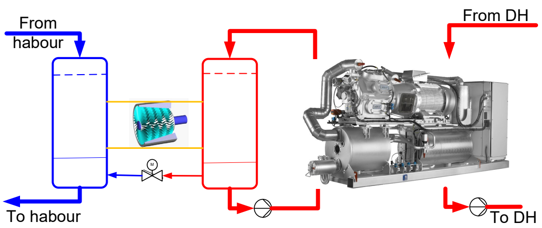
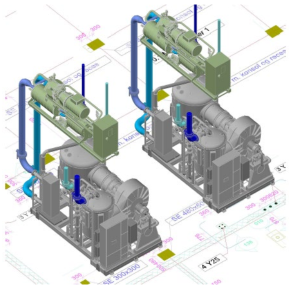
Heat Pump installation at Aarhus Ø

- Cascade system with water vapor direct evaporation from sea water as heat source.
- Sabroe ammonia HeatPAC's on second stage





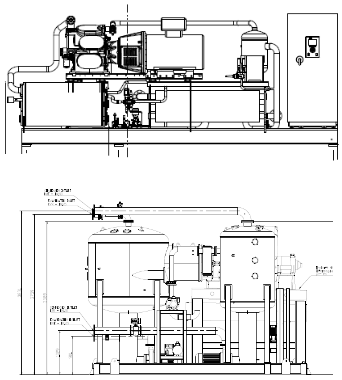
x 12

Key facts and figurs

<u>HeatPAC:</u>
Heat yield: 1070kW
El Power HT: 175kW

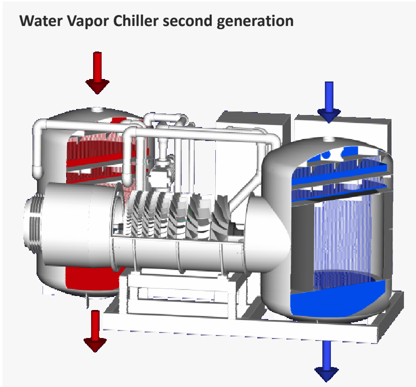
<u>Water Vapor Chiller</u>
Cooling yield: 790kW
El power LT: ~150kW

<u>Total LT+HT</u>
COP_{heat} : 3,30



Water Vapor – Key Features

- Chiller that brings unique features:
  - Close to zero refrigerant costs, always available
  - Direct evaporation and condensing possible; eliminates heat exchangers fouling –useful for sea water!
  - Inherent safe, Non-pressure vessels, outside PED
  - Patented high efficient vacuum system
  - No skilled refrigeration service technician needed. Just a plumber...
  - Heart of technology is unique axial turbo compressor
  - Water-lubricated compressor, no other substances needed.
  - State-of-art efficiency



Water Vapor Chiller

Water Vapor Heatpump with 7-stages compressor (Low stage)

With the following data :

Refrigerant		:	R718 Water
Length x width x height	[m]	:	5.3 x 3.2 x 3.95
Weight, without refrigerant	[kg]	:	10.500
Compressor		:	7-stages axial turbo
Speed	[rpm]	:	14.300
Capacity	[m3/s]	:	42
Shaft power	[kW]	:	Max. 165 kW
Capacity control	[%]	:	Stepless

Process specifications	May 7th	May 13th	May 14th
Power consumption, compressor	120 kW	128 kW	130 kW
COP compressor, heating	6.4	6.4	6.4

All values are average values of several measurements.

Evaporator : Liquid cooled, direct type
Cooled media : Sea water

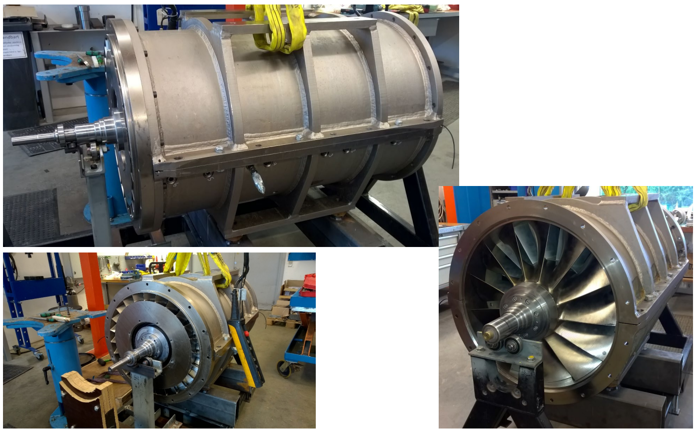
Process specifications	May 7th	May 13th	May 14th
Cooling capacity	629 kW	667 kW	668 kW
Sea water temperature	9.2 °C	10.4 °C	10.5 °C
Temperature leaving	5.3 °C	6.2 °C	6.4 °C
Evaporating pressure	8.1 mbar	11.2 mbar	11.8 mbar
Volume flow	140 m3/h	140 m3/h	140 m3/h

All values are average values of several measurements.

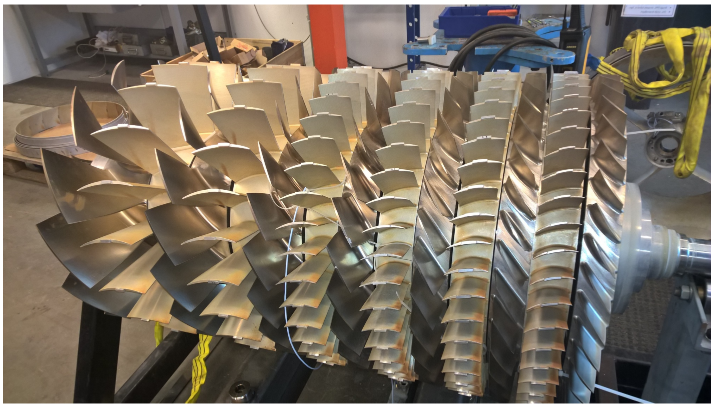
Condenser : Liquid cooled, direct type
Heated media : Water

Process specifications	May 7th	May 13th	May 14th
Heating capacity	770 kW	820 kW	830 kW
Temperature leaving	28.9 °C	30.6 °C	31.1 °C
Temperature return	25.3 °C	26.9 °C	27.2 °C
Condensing pressure	41.2 mbar	45.6 mbar	46.7 mbar
Volume flow	185 m3/h	185 m3/h	185 m3/h

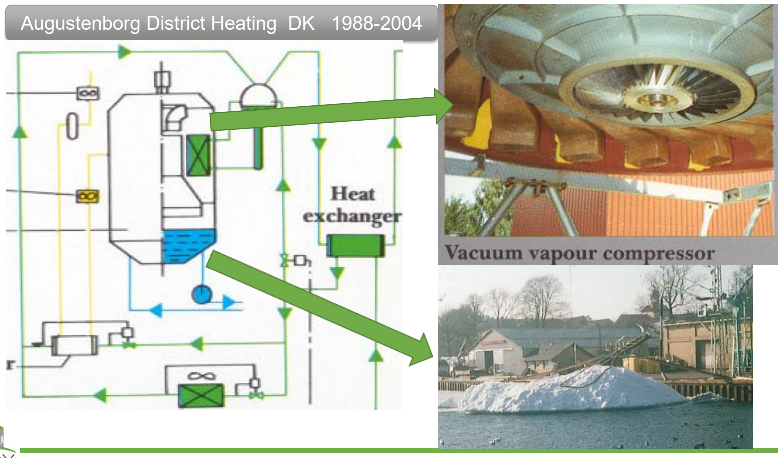
Water Vapor Compressor



Rotor/stator



The sea as inexhaustable all-year source, even at 0°C!



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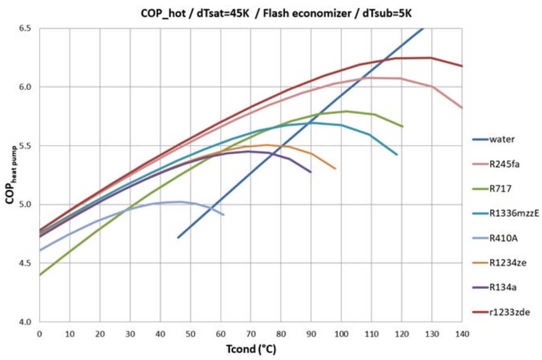
Water for High Temperature Heat Pumps - Perspectives

Can we find a **refrigerant for Heat Pump around 100°C** that has:

- High COP
- Low pressure, around ambient
- No environmental or safety issues
- Low cost

Water !



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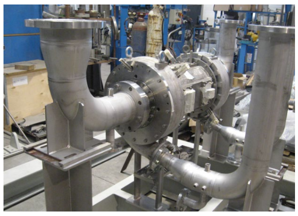
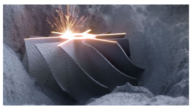
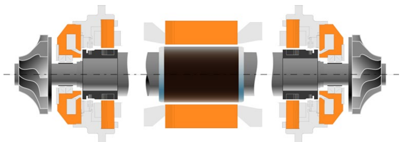
PACO compressor

Manufacturing of **PACO** compressor

- 150kW permanent magnet motor
- 40000 RPM
- Magnetic bearings
- 2 stages with 2 scrolls
- Variable Speed Drive
- Titanium impellers built from additive manufacturing







15

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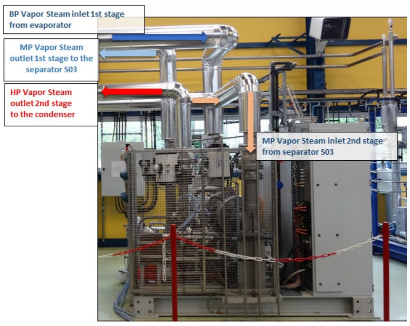
Partnership with "EDF" France

Testing at "EDF" research center



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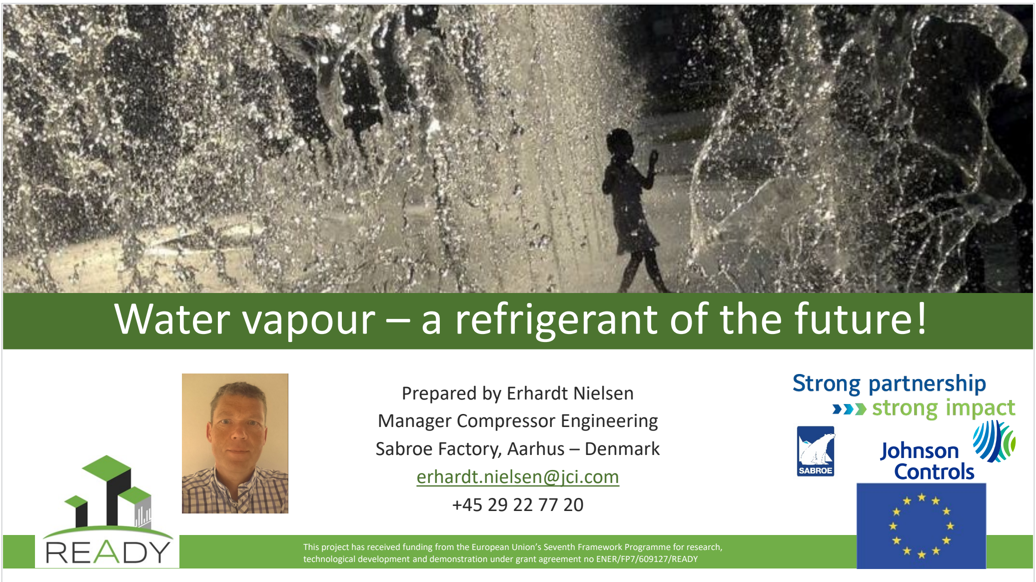
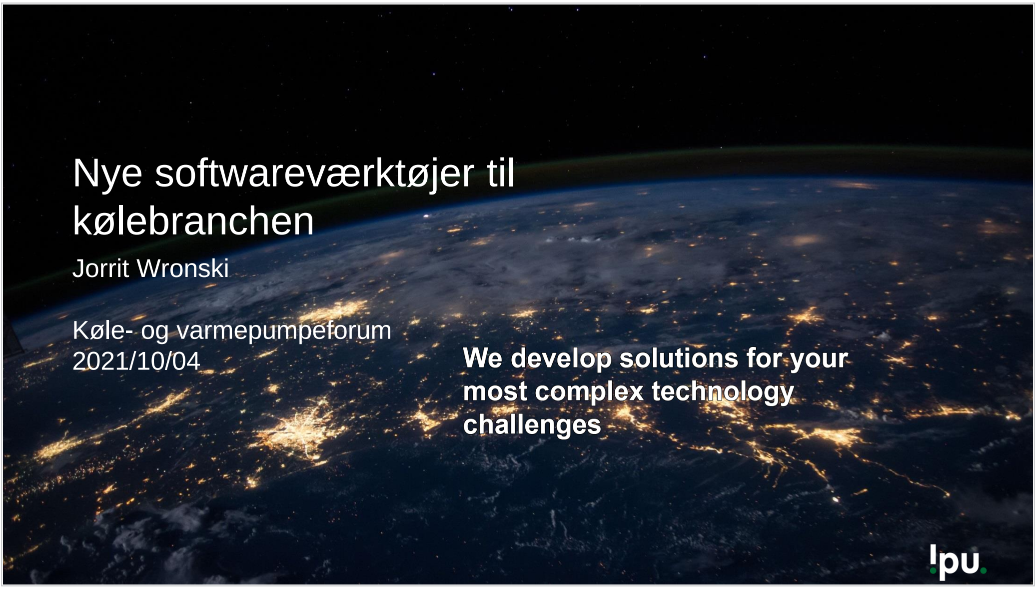
Johnson Controls


Water vapour – a refrigerant of the future!
Prepared by Erhardt Nielsen
Manager Compressor Engineering
Sabroe Factory, Aarhus – Denmark
erhardt.nielsen@jci.com
+45 29 22 77 20
Strong partnership
strong impact
SABROE
Johnson Controls
READY
This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement no ENER/FP7/609127/READY



Agenda

- Software for Refrigeration and Heat Pumps
- IPU and software activities
- CoolTools
- User journey and Pack Calculation Pro

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Software for Refrigeration and Heat Pumps

- Purpose of software tools
  - **Energy efficiency**
    - Focus on energy consumption
    - Integration with other systems
  - **Data analysis**
    - Monitoring
    - Fault detection
    - Optimization
  - **New refrigerants**
    - Retrofits and compatibility
    - Control and performance
  - **New components**
    - Component performance
    - Cycle layouts and control
- Computational time scales
  - **User interaction**
    - Cycle visualization
    - Component analysis
  - **Numerical studies**
    - Component selection
    - System tuning
  - **Close to real-time**
    - Plant control
    - Online optimization

Who are IPU?

- A small company that bridges the gap between research and business since 1956.
- We are located on the campus of the Technical University of Denmark (DTU).
- IPU work with 5 key areas:
  - Advanced Materials & Surfaces Technology
  - Thermodynamics and Energy Technology
  - Autonomous Systems and Robotics
  - Modelling of Physical Systems
  - Product- and Process Technology Development
- IPU have a long history in developing software solutions for refrigeration engineers.

Refrigeration Software Activities

Development of refrigeration and heat pump software for customers like Danfoss, Emerson, Maersk Line, Nilan, …

Delivering high performance utility libraries for fluid properties compatible with MS Excel, EES, Modelica: ASEREP, CoolProp, ExternalMedia

Custom calculation models development in Python, C/C++/C#, Pascal/Delphi and for PLC and embedded systems: CO_2 with solid region, component performance, …

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Refrigeration Software Overview

Ongoing development:

- Pack Calculation Pro: annual performance of refrigeration systems
- CoolTools: simplified simulation models with modern refrigerants

Legacy downloads at https://www.ipu.dk/:

- CoolPack: simplified simulation models for refrigeration engineers and students
- SecCool: properties of secondary refrigerants and heat transfer media
- Simple one-stage CO_2: educational program for transcritical CO_2 cycle

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CoolTools
2021/10/04
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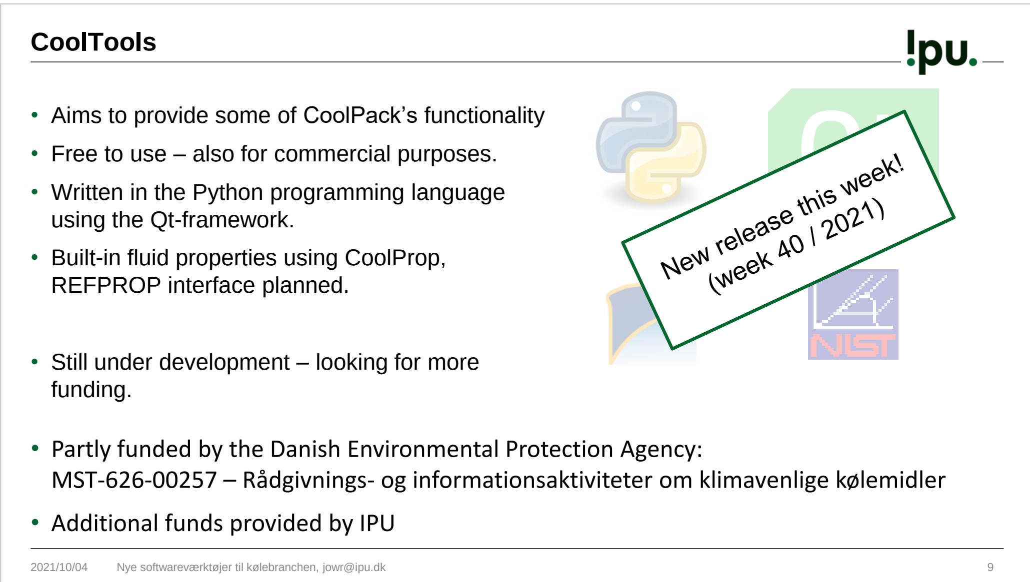
ipu.
7


CoolTools
ipu.
• Aims to provide some of CoolPack's functionality
• Free to use – also for commercial purposes.
• Written in the Python programming language using the Qt-framework.
• Built-in fluid properties using CoolProp, REFPROP interface planned.
• Still under development – looking for more funding.
New release this week! (week 40 / 2021)
NIST
• Partly funded by the Danish Environmental Protection Agency: MST-626-00257 – Rådgivnings- og informationsaktiviteter om klimavenlige kølemidler
• Additional funds provided by IPU
2021/10/04
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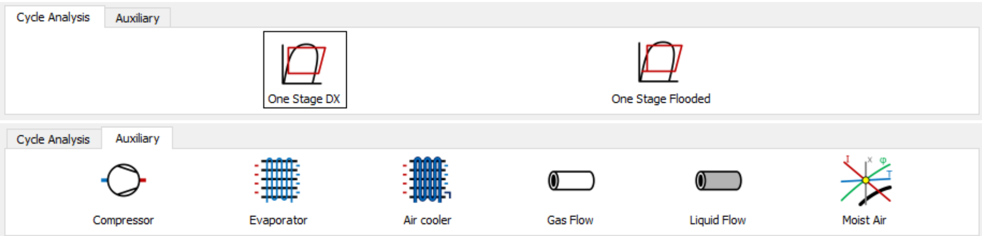
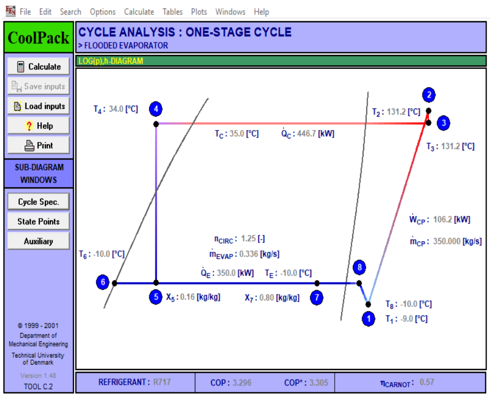
9

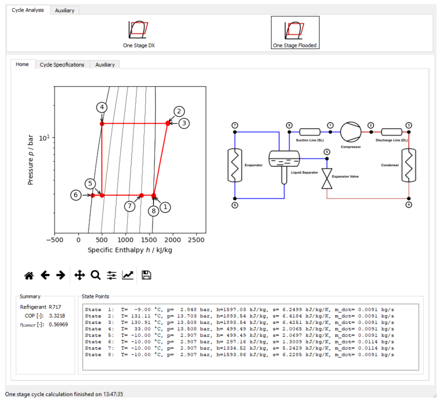
Currently included calculations

- **Cycle Analysis**
  - One stage with DX evaporator
  - One stage with flooded evaporator
- **Auxiliary**
  - Compressor
  - Evaporator
  - Air cooler
  - Gas and liquid pipe flow
  - Moist air

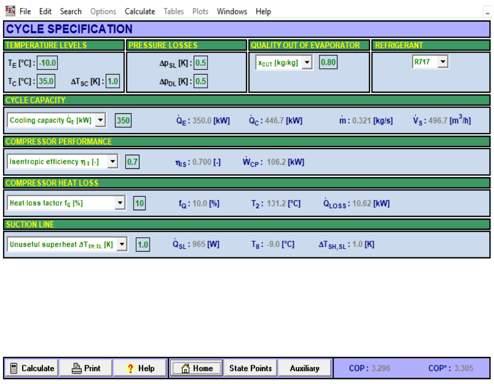


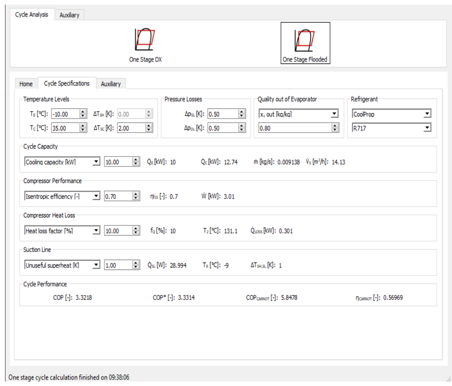
Cycle Analysis – One stage cycle with Flooded Evaporator





Cycle Analysis – One stage cycle with Flooded Evaporator





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Comparison of Cycle Results

- Dry expansion

	CoolTools	CoolPack
T_2 [ºC]	56.05	55.3
T_4 [ºC]	33.15	32.6
x_6	0.36	0.36
Q_C [kW]	187.87	187.3
Q_E [kW]	139.95	139.8
W [kW]	46.8	46.1
COP	2.99	3.012

- Flooded evaporator

	CoolTools	CoolPack
T_2 [ºC]	131.1	131.2
Q_C [kW]	12.74	12.8
m [kg/s]	0.00931	0009
W [kW]	3.01	3
COP	3.32	3.296

- Noticeable differences:
  - Instant processing – no calculation button.
  - Real pressure-enthalpy diagram, no sketch.

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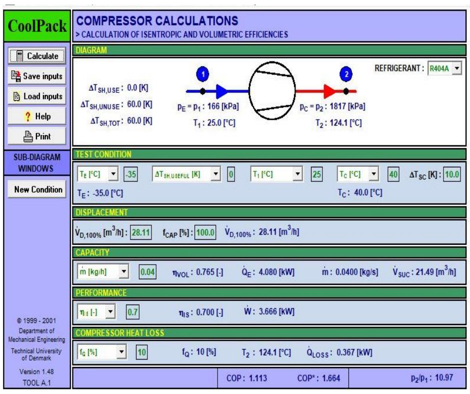
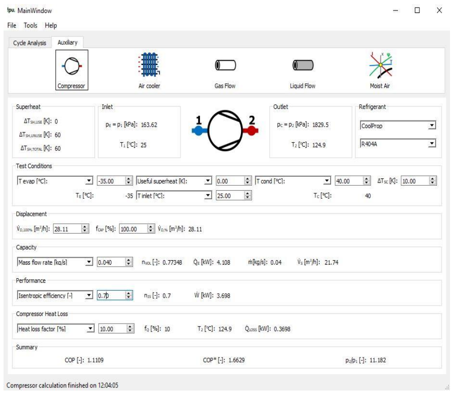
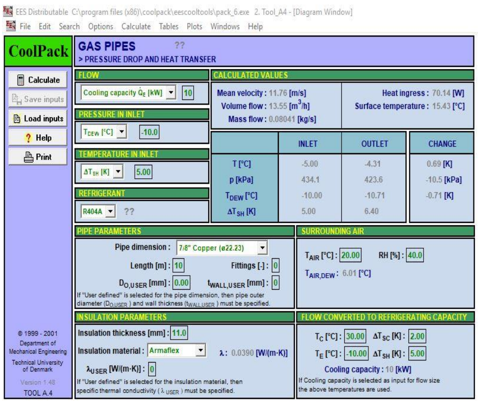
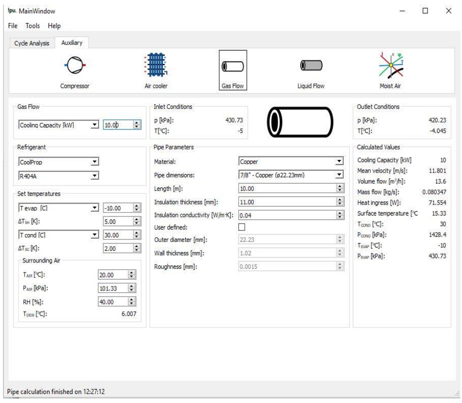
Auxiliary – Compressor





Auxiliary – Gas Pipes





Comparison of additional Results

- Compressor calculation

	CoolTools	CoolPack
T_2 [ºC]	124.9	124.1
p_2 [Pa]	1829.5	1817
n_{VOl} [-]	0.774	0.765
Q_E [kW]	4.14	4.08
W [kW]	3.697	3.666
COP	1.12	1.113

- Gas pipe flow

	CoolTools	CoolPack
Mean velocity [m/s]	11.76	11.76
Volume flow [m^3/s]	13.6	13.55
Mass flow [kg/s]	0.08035	0.08041
Heat ingress [W]	71.55	70.14
T_{OUTLET} [ºC]	-4.045	-4.31
Surface temperature [ºC]	15.33	15.43

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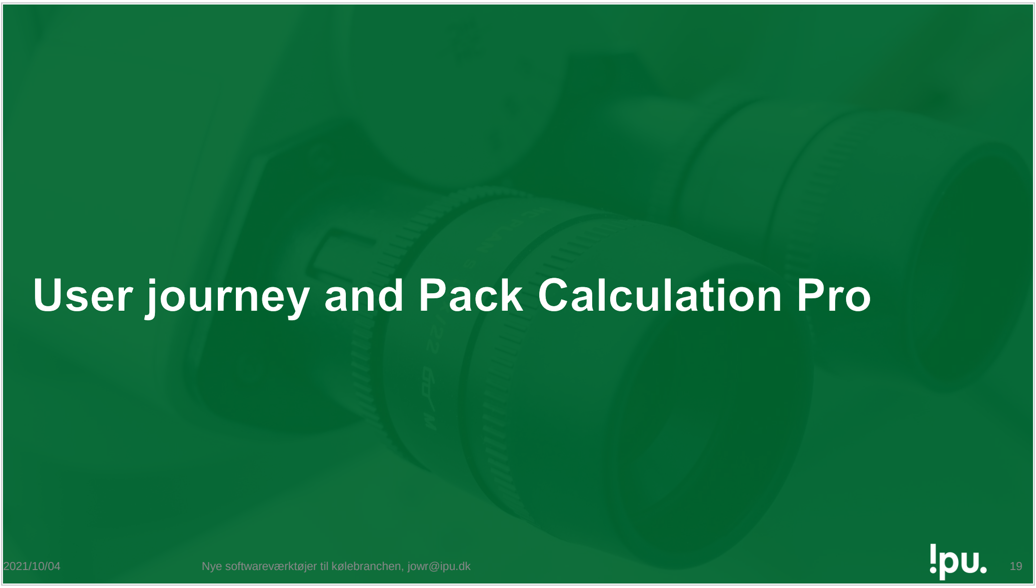
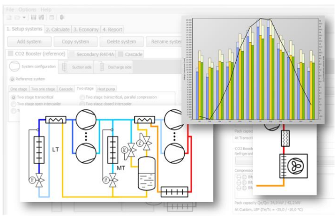


Pack Calculation Pro

- Minimum required input data (customization is still possible).
- Calculate performance each hour of the year (= 8760 operating points)
- Weather data for more than 3700 cities around the world
- 11 commonly used cycles (including parallel compression and transcritical cycles)
- Choose from 10000 commercially available compressor to build your system
- Calculate Life Cycle Costs and payback time
- Get an overview of both energy consumption and carbon footprint
- Create reports and export plots and data
- And much more!



EU-project “SuperSmart Supermarket” concludes:
… it [Pack Calculation Pro] is one of the most useful tools for planning the refrigeration system, since it includes many desired features (component database, user-friendly interface, automatic report generation) and also recent refrigeration system layouts.

User Voices and Feedback

- This time, we do not focus on the technical details, instead we look at the different types of software users.
- Here are some examples for the feedback that we received for Pack Calculation Pro:

Contractor XY

“I have to provide too much information.”

“I cannot find my way around the software.”

Engineer XY

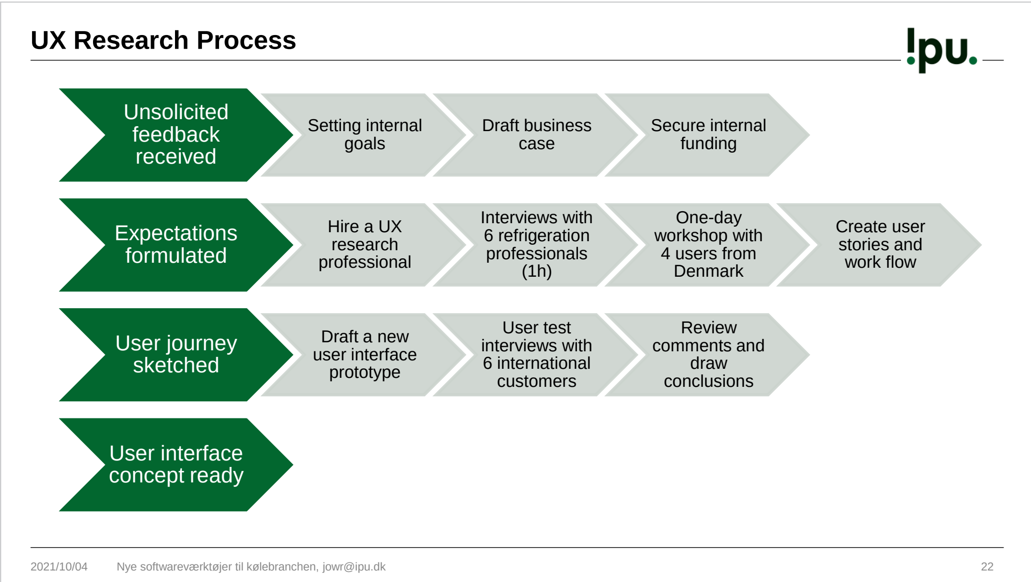
“We have to calculate component sizes and prices early on.”

“How can I keep track of my own selection criteria?”

Consultant XY

“Custom reporting is key for good customer interactions.”

“I need a tool to define the cooling demand.”


UX Research Process
Unsolicited feedback received
Setting internal goals
Draft business case
Secure internal funding
Expectations formulated
Hire a UX research professional
Interviews with 6 refrigeration professionals (1h)
One-day workshop with 4 users from Denmark
Create user stories and work flow
User journey sketched
Draft a new user interface prototype
User test interviews with 6 international customers
Review comments and draw conclusions
User interface concept ready
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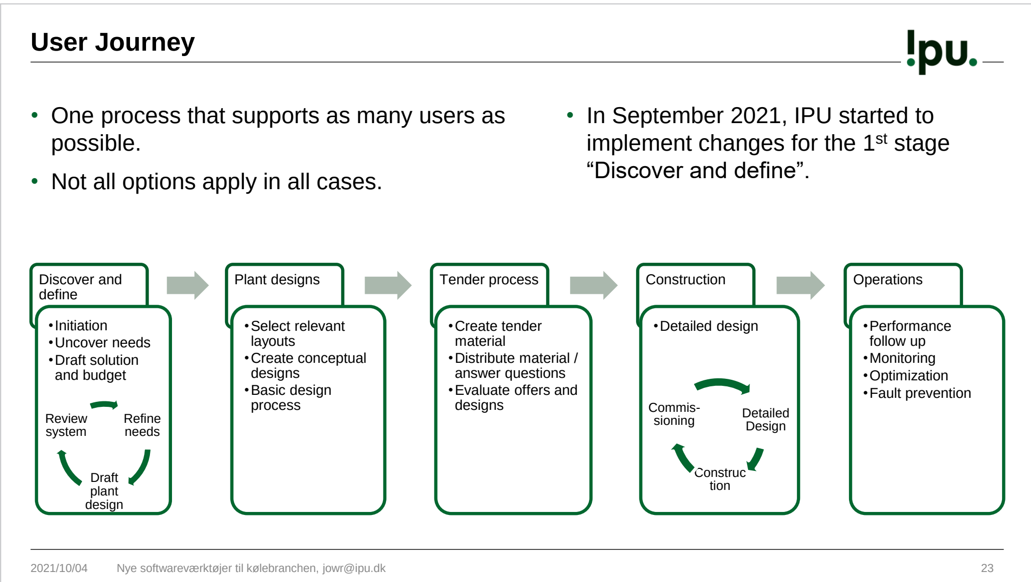
User Journey
• One process that supports as many users as possible.
• Not all options apply in all cases.
• In September 2021, IPU started to implement changes for the 1st stage "Discover and define".
Discover and define
• Initiation
• Uncover needs
• Draft solution and budget
Review system
Refine needs
Draft plant design
Plant designs
• Select relevant layouts
• Create conceptual designs
• Basic design process
Tender process
• Create tender material
• Distribute material / answer questions
• Evaluate offers and designs
Construction
• Detailed design
Commis-sioning
Detailed Design
Construc tion
Operations
• Performance follow up
• Monitoring
• Optimization
• Fault prevention
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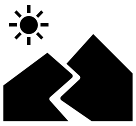
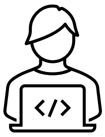
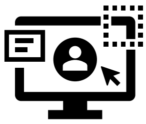
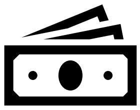
Ongoing Activities and future Work

- Pack Calculation Pro:
  - From single-shot system simulation to iterative plant design.
  - Focus on early results. Provide estimates for dimensioning and budget.
  - New component: Cooling and heating demand profile wizard.
- CoolTools:
  - IPU implement small changes along the road.
  - Larger additions require additional funding.

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Thank You! Questions?

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Thermodynamic Modelling Specialist
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jowr@ipu.dk / www.ipu.dk
Dir. +45 45 16 04 26

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3 7th International Symposium on Advances in Refrigeration and Heat Pump Technology

1.1 Trends in Refrigeration and Heat Pump Technology, Riley Barta, Technische Universität Dresden, Germany

1.2 A new flow modulation technique for R744 two-phase ejectors, Paride Gullo, University of Southern Denmark

1.3 Second generation direct drive vaccine cooler, Ivan Katic, Danish Technological Institute

1.4 High Temperature Heat Pump System based on water vapor, Hans Madsbøll, Danish Technological Institute item On the influence of air recirculation in large-scale air-source heat pumps Brice Rogié, DTU Mechanical Engineering

1.5 Mixed refrigerant heat pumps – combined selection of working fluids and cycle layouts, Jonas Kjær Jensen, DTU Mechanical Engineering

1.6 FARS - Future ammonia refrigeration system, Niels P. Vestergaard, Danfoss A/S

1.7 Experimental investigation on the thermal management of electronics by flow boiling of refrigerants in copper multi-microchannels, Gennaro Criscuolo, DTU Mechanical Engineering

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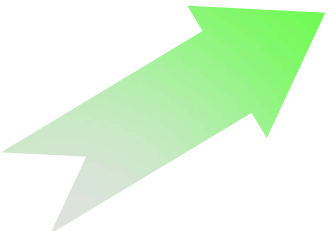
Dr. Riley B. Barta
Bitzer Chair for Refrigeration, Cryogenics and Compressor Technology

Trends in Refrigeration and Heat Pump Technology

7th International Symposium on Advances in Refrigeration and Heat Pump Technology
Copenhagen, Denmark
October 4th, 2021

Trends

What is a Trend ?



Trend is a direction of a change process

- Surface phenomena (e.g. product trends)
- severe, sustaining directions (e.g. Mega Trends).

For judgement of future developments

Energy and CO_2 Emissions

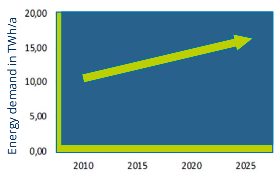
Energy

Refrigeration, A/C and heat pumps:

- 15 % el. energy consumption
- Increasing energy demand, e.g.:
  - A/C
  - Data Centers

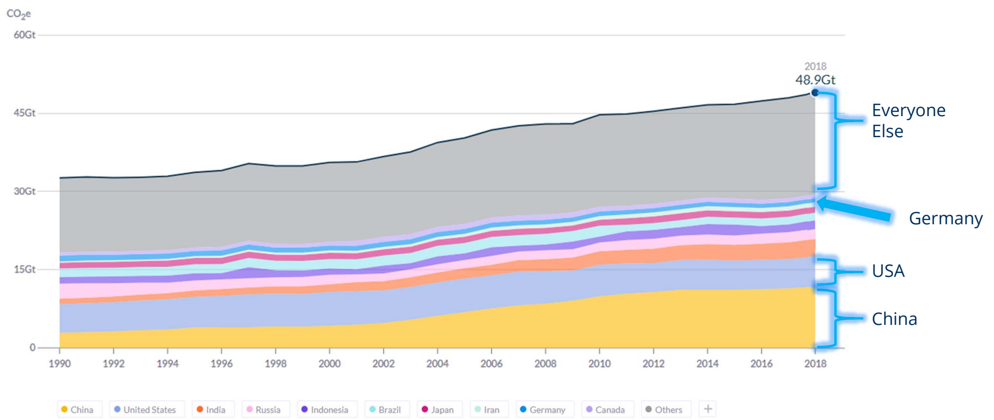
IEA report "*The Future of Cooling*"

Global **energy demand** from air conditioners is expected to **triple by 2050**, requiring new electricity capacity the equivalent to the combined electricity capacity of the United States, the EU and Japan today.



Energy consumption German data centers

CO_2 Emissions Worldwide, Per Year: 1990 - 2018



[Climatewatchdata.org]

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Riley Barta
7th Int'l Symposium on Advances in Refrigeration and Heat Pump Technology, October 4th, 2021

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CO_2 Emissions - Awareness and Legal Measures

Germany: *Klimaschutzgesetz* of May 12th, 2021 (climate protection law)

by 2030: 65 % less CO_2 emissions (basis 1990)

by 2040: 88 % less CO_2 emissions (basis 1990)

USA: American Innovation and Manufacturing (AIM) Act September 23rd, 2021

U.S. Production and Consumption of HFCs to be reduced by 85% over the next 15 years

News Releases from Headquarters

U.S. Will Dramatically Cut Climate-Damaging Greenhouse Gases with New Program Aimed at Chemicals Used in Air Conditioning, Refrigeration

September 23, 2021

Contact Information
EPA Press Office (press@epa.gov)

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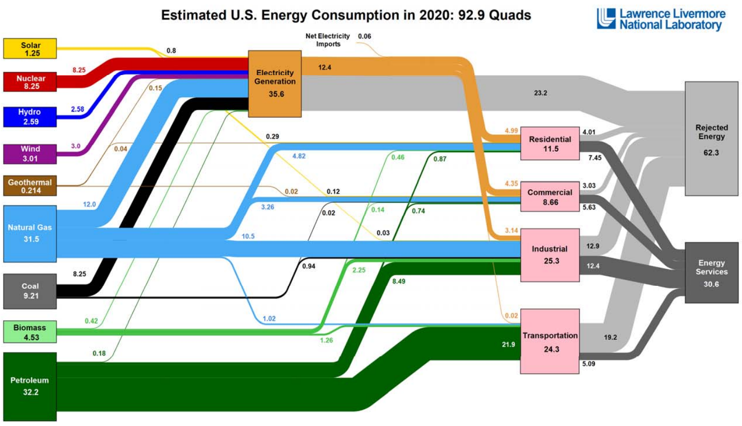
Energy Flow USA



1 Quad = 1 x 10^{15} BTU

1 PJ = 1 x 10^{15} J

1 Quad ≅ 1055 PJ

92,9 Quads ≅ 98.000 PJ

[LLNL]

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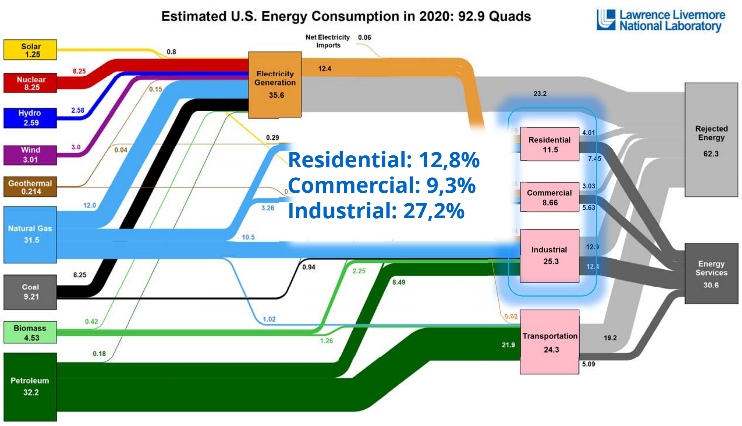
Energy Flow USA



Significant usage of Thermal energy

Refrigeration,
Cooling,
Space heating,
Tap water heating,
Process heat,
...

[LLNL]

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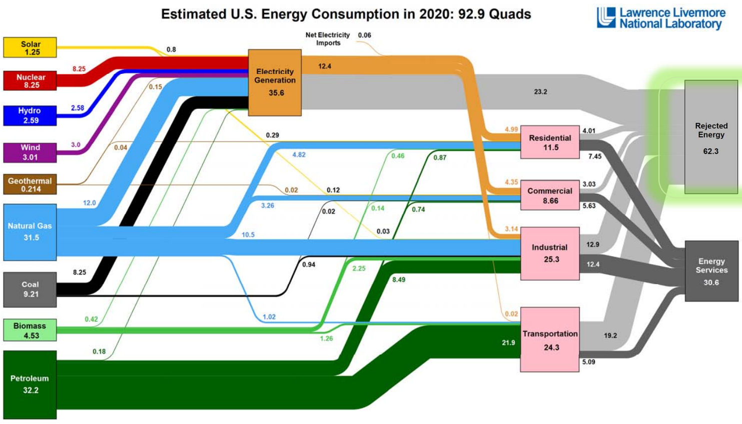
Energy Flow USA



Rejected Energy 67%

Potential for…
WHR,
Heat pumps,
ORCs,
…

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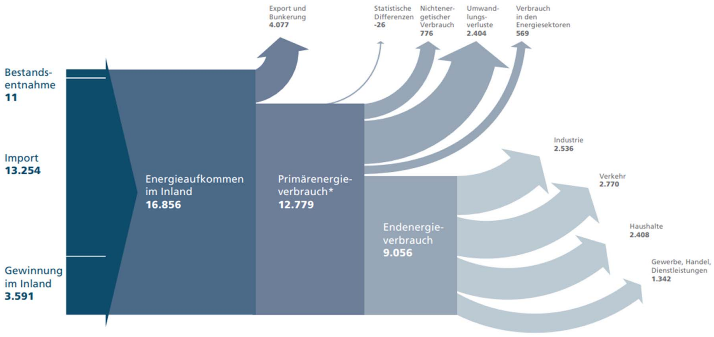
Energy Flow Germany

Energieflussbild 2019*
für die Bundesrepublik Deutschland
in Petajoule (PJ)



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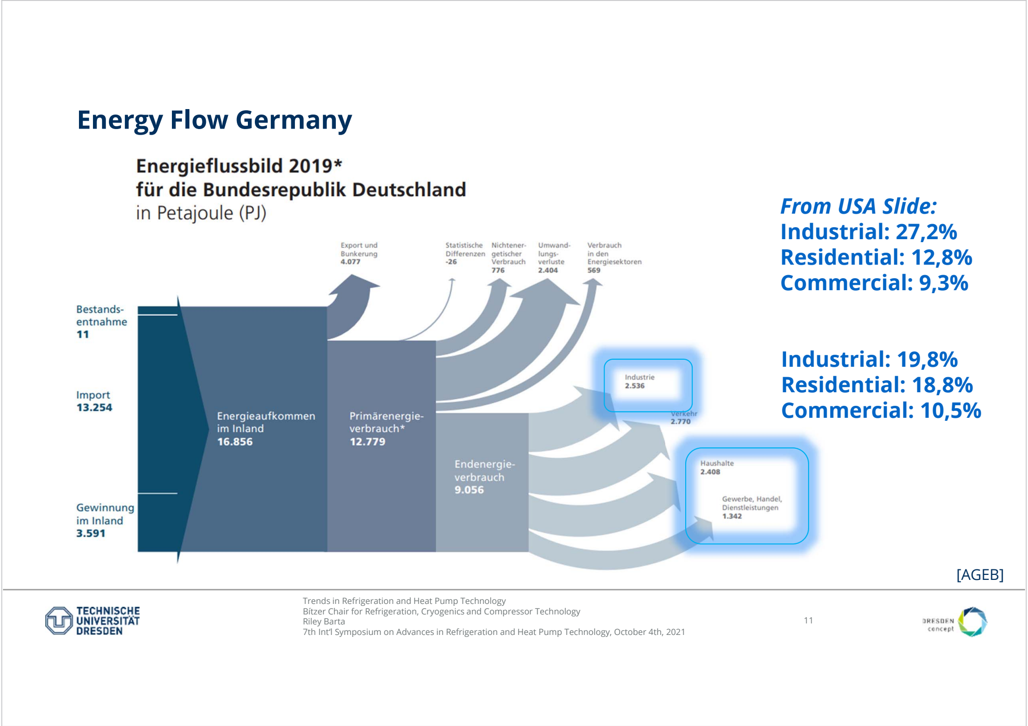

Energy Flow Germany
Energieflussbild 2019*
für die Bundesrepublik Deutschland
in Petajoule (PJ)
Export und Bunkerung 4.077
Statistische Differenzen -26
Nichtenergetischer Verbrauch 776
Umwandlungsverluste 2.404
Verbrauch in den Energiesektoren 569
Bestandsentnahme 11
Import 13.254
Gewinnung im Inland 3.591
Energieaufkommen im Inland 16.856
Primärenergieverbrauch* 12.779
Endenergieverbrauch 9.056
Industrie 2.536
Verkehr 2.770
Haushalte 2.408
Gewerbe, Handel, Dienstleistungen 1.342
From USA Slide:
Industrial: 27,2%
Residential: 12,8%
Commercial: 9,3%
Industrial: 19,8%
Residential: 18,8%
Commercial: 10,5%
[AGEB]
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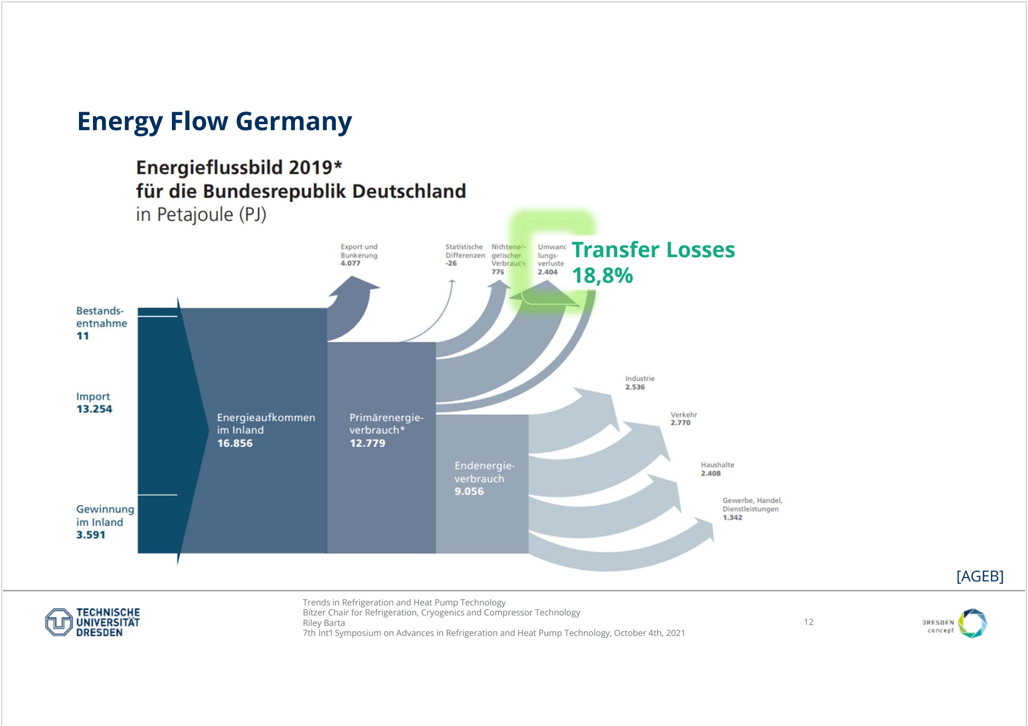

Energy Flow Germany
Energieflussbild 2019*
für die Bundesrepublik Deutschland
in Petajoule (PJ)
Export und Bunkerung 4.077
Statistische Differenzen -26
Transfer Losses
18,8%
Bestandsentnahme 11
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[AGEB]
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Refrigerants

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13

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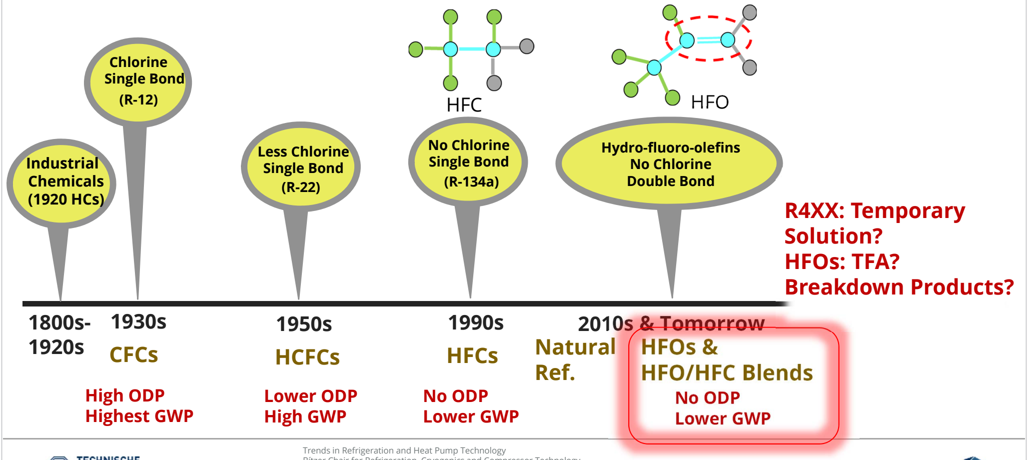
Historical Review of Refrigerants



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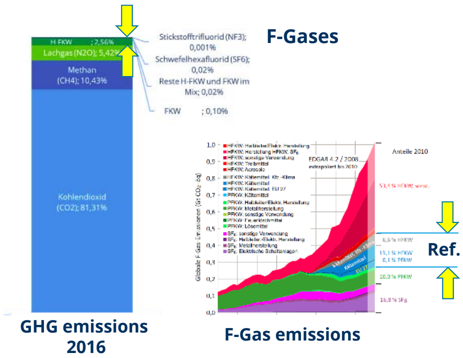
Energy and CO_2 Emissions – Influence of Refrigerants

in CO_2 equivalent:

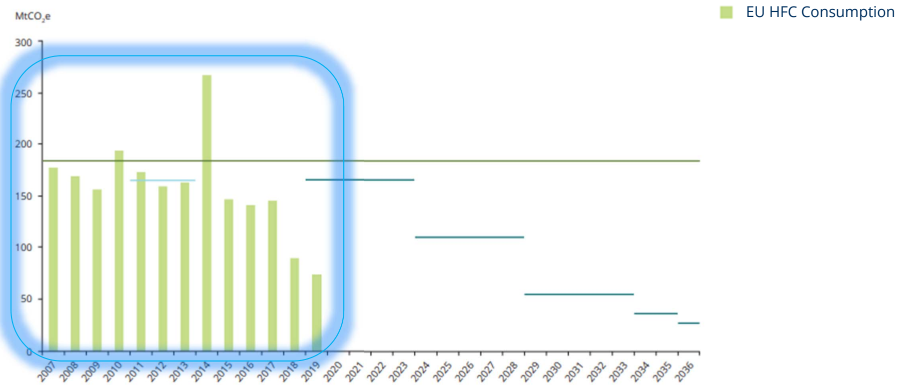
- F-Gas ca. 2,5 % of total GHG emissions
- Refrigerants ca. 20% of global F-Gas emissions
- Refrigerant emissions: about 0,5 % of total GHG emissions

➢ Energy consumption and CO_2 emissions are the key
- as long as energy is non-renewable -



[EEA]

EU Progress with F-Gas Phasedown



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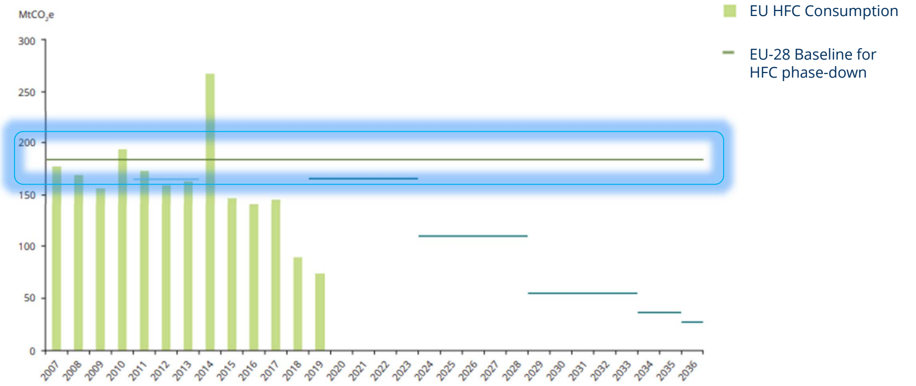
EU Progress with F-Gas Phasedown



[EEA]

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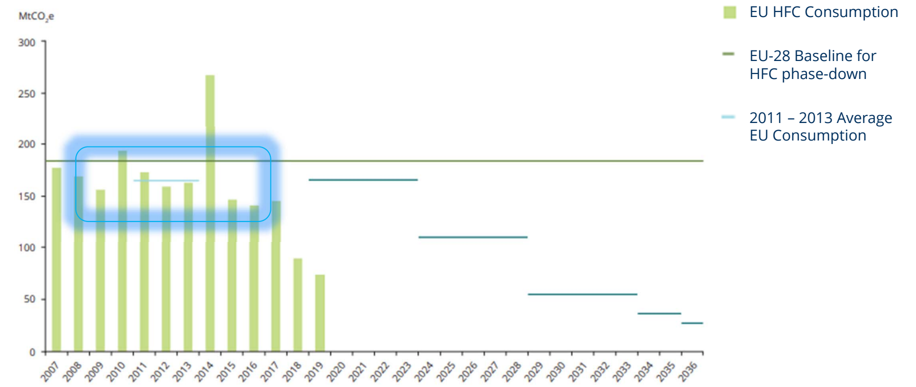
EU Progress with F-Gas Phasedown



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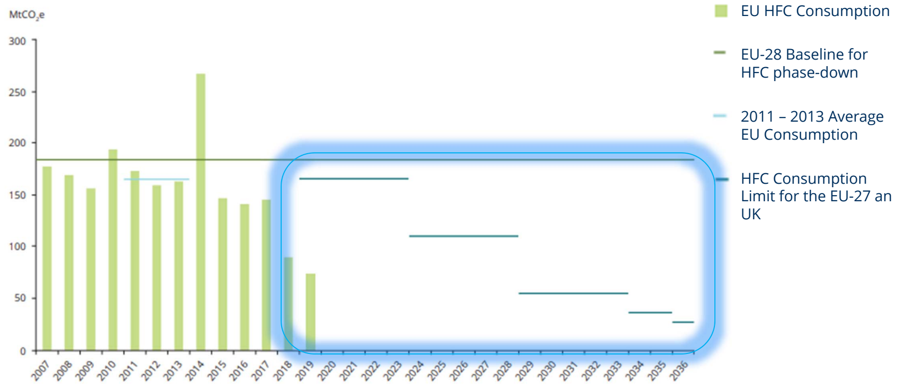

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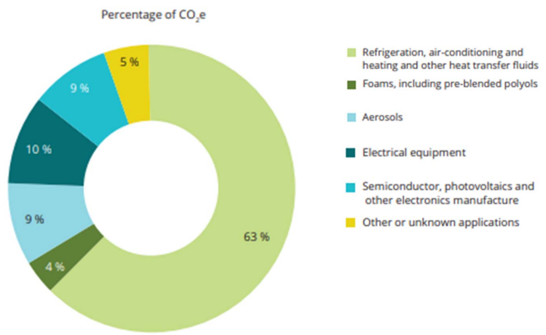
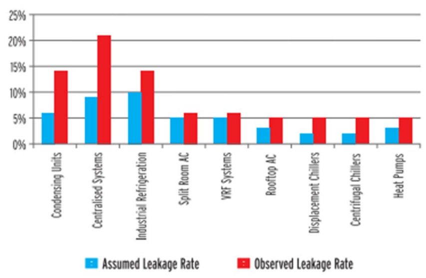
F-Gas Usage in the EU: Further Perspectives

2019: EU Supply by Intended Applications



Leakage Observations



[EEA] [EIA]

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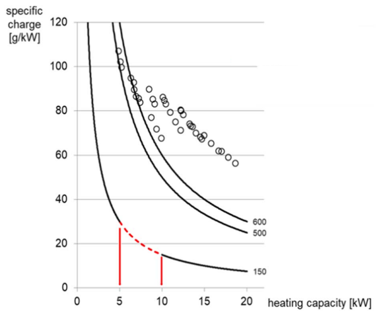
Flammable Refrigerants

Safety measures:

- Charge reduction
- Housing and ventilation
- Outside installation
- Reduction of oil charge
- Omission of oil
- Other measures

150 g propane charge, 8 kW heat pump

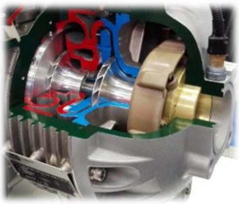


[Dankwerth et al., 2020]

Flammable Working Fluids

Oil-free, dry running compressors

➢ Risk: Oil reduces the ignition temperature significantly *



1 kW, Π 3.4, 280 krpm **

Sources: *) Risk Assessment of Mildly Flammable Refrigerants, Final Report 2016, The Japanese Society of Refrigerating and Air Conditioning Engineers
Dang C.et al.: Diesel Combustion of Oil and Refrigerant Mixture during Pump Down of Air Conditioners, ICR 2015, Yokohama
**) J. Schiffmann: Gas Bearings for Turbocompressors, 1st Innovation Day of Compressor Technology, TU-Dresden, Okt.2017

International Perspectives
Education

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How do we continue to motivate and recruit students?

- In Germany and the US, we are seeing decreased recruitment rates
- How to connect the energy crisis with this technology from a *younger age* (Before Uni)?
- Connections with industry *during* Education
- Competitions open to Universities

ENGINEERS WITHOUT BORDERS USA

„Chill Challenge" – Affordable, Off-Grid Refrigeration

Global Cooling Prize

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Application Examples

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Perspective: Bridging the Gap Between Academia and Industry

For a given modification, solution or invention:

- *Relevance*
  - Solution to an existing problem?
  - Or a solution looking for a problem?

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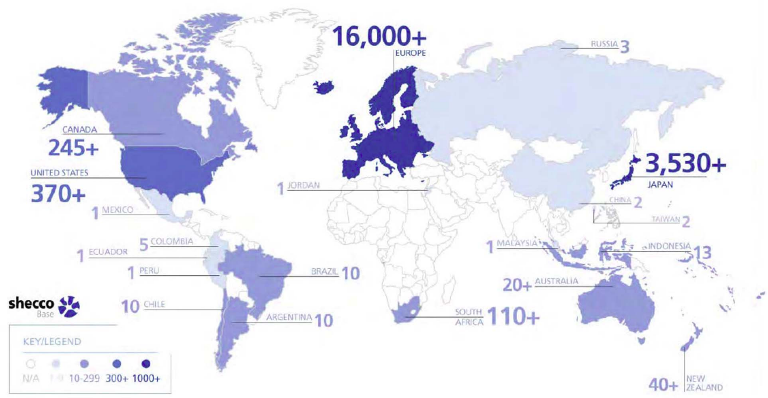
Application Examples

Supermarkets

CO_2 Refrigeration Systems: Progress of Acceptance



[Shecco, Skacanova 2018]

Challenges for CO_2 Refrigeration Systems

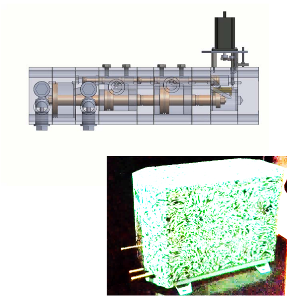
Low COP at high ambient temperatures

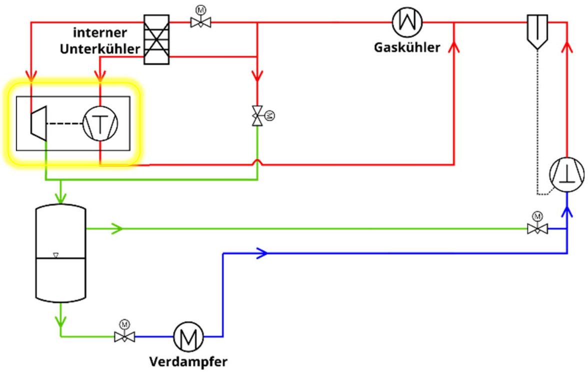
Target
- Competitive efficiency at high temperature climates
- Shift of the CO_2 equator to the south

➢ Analyses of improvement options

Efficiency Improvement and System Comparison

Expander Compressor Unit

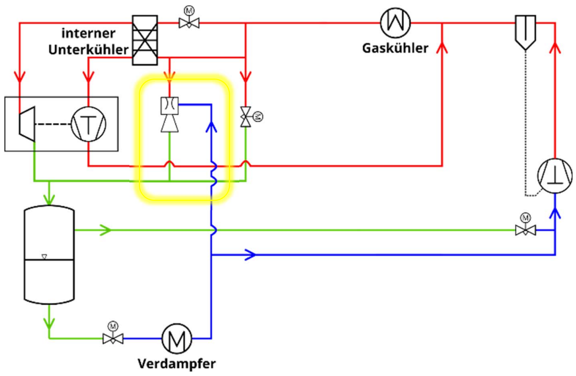




Efficiency Improvement and System Comparison

Ejectors
- High lift
- Low lift

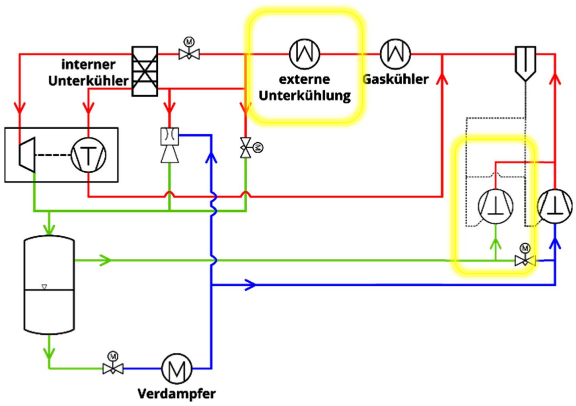
Ejektor /Carel/



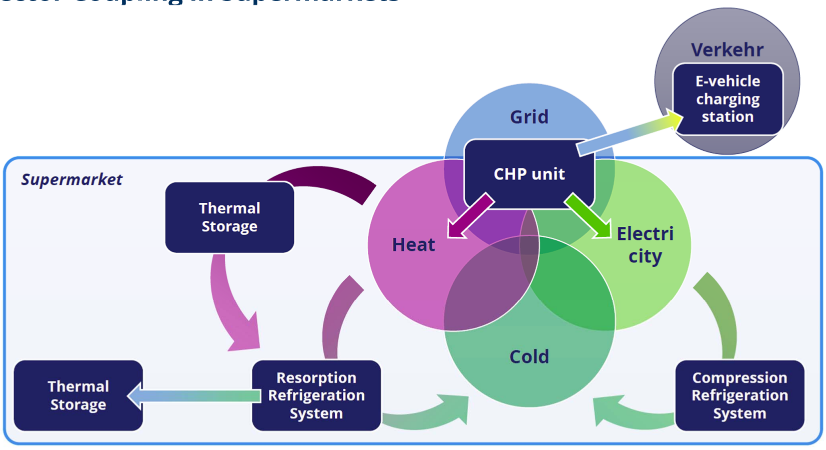
Efficiency Improvement and System Comparison

- External subcooling
- Parallel compression

All tests at different ambient and load conditions



Sector Coupling in Supermarkets



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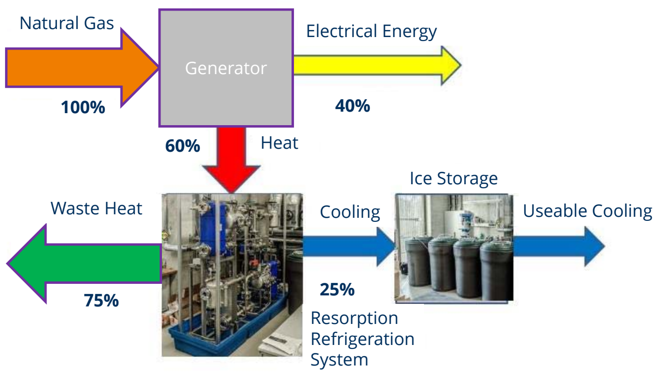
Resorption System



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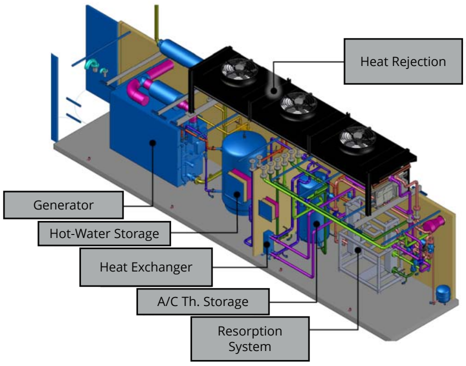
Resorption System

- Ammonia – Water system
- Field Test near Stuttgart
- Reduced operating costs for electricity and heat by *more than 40%*



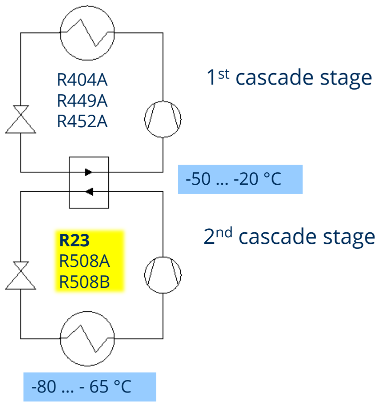
Application Examples
Ultra-Low Temperature

Task and Applications

- F-Gas Regulation: *Exception* for Ultra-Low Temperature Applications
  - Article 13, (3)
  - Annex III, (12)

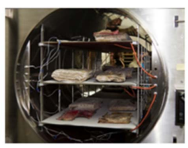
- „… with a global warming potential of 2500 or more… shall be prohibited.“
  - „This paragraph **shall not apply to** …. Or equipment intended for applications designed to cool products to temperatures **below –50 °C**.“

Task and Applications



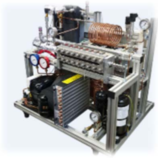
Applications:
- Lab. thermostat
- Climatic test chamber
- Freeze drying systems
- Vaccine cooler
- …



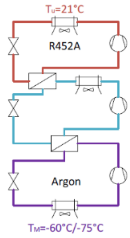


Non-Flammable Solutions

R744 Sublimation



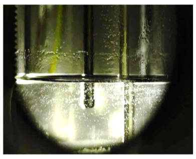
Secondary fluids



Sub-atmospheric pressure systems

R744 mixtures

- R469A (R744/R32/R125) - GWP of 1357, *high glide*
- R473A (R23/R1132a/R744/R125) - GWP of 1830, *low glide*



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High Temperature Heat Pump

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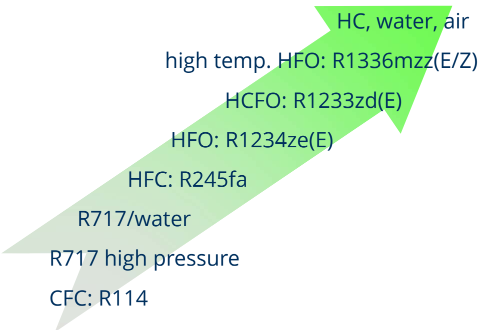
High Temperature Heat Pump



R245fa heat pump for drying application

[CombiTherm]

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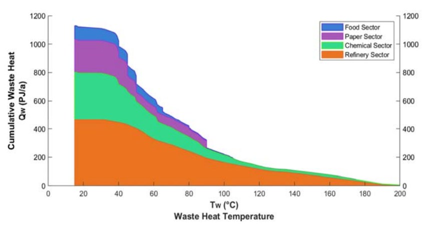
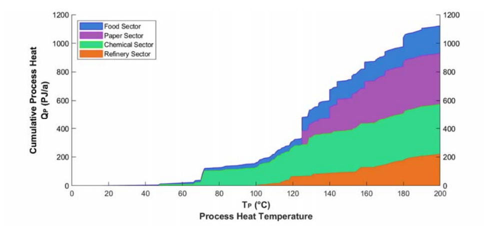
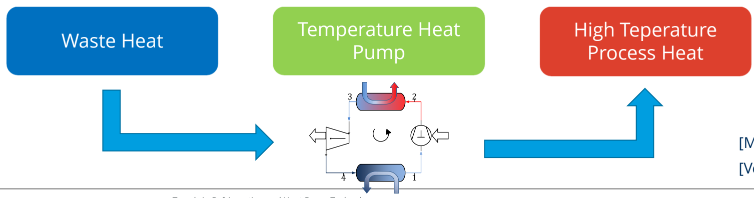
Heat Sources and Temperatures







[Marina et al., 2021]
[Venzik 2021]

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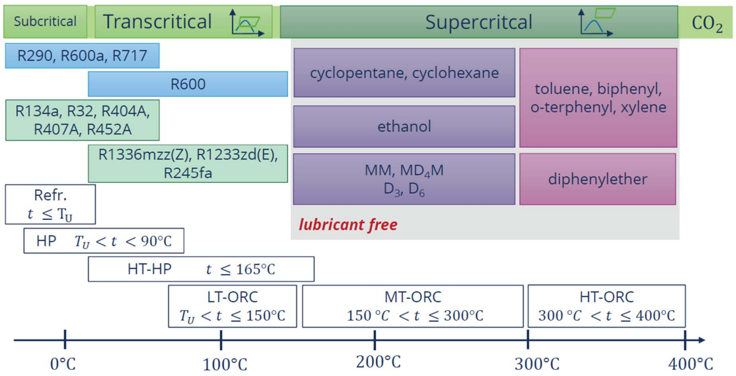
Groups of HP- and ORC-Working Fluids

Application and Temperature Ranges



[Hesse 2020]

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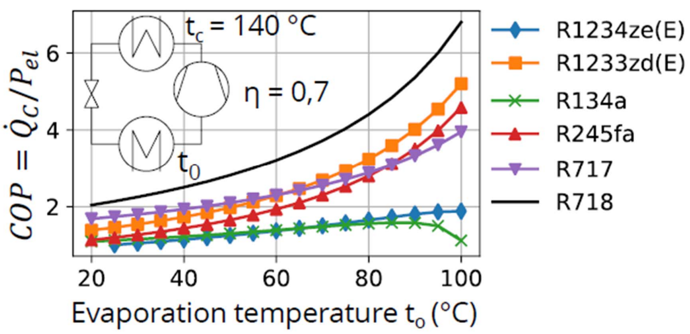
High Temperature Heat Pump Performance Estimates



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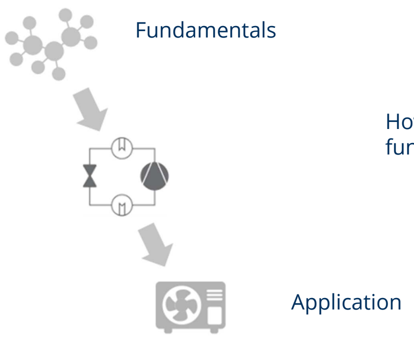
Application Examples
Household Appliances

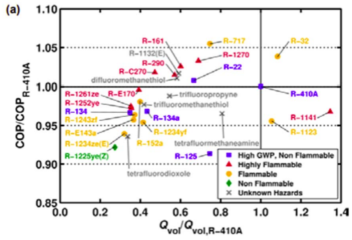
As the problems become more complicated…



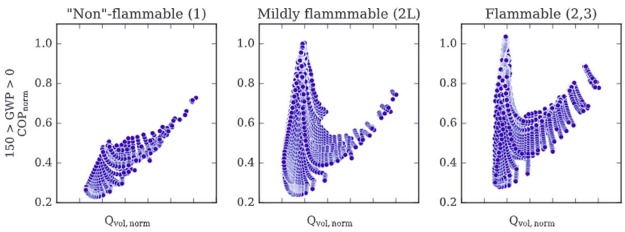
How much further in the direction of fundamentals do we need to go?

Investigation of Suitable Refrigerants

- How many more combinations of existing refrigerants can we find?



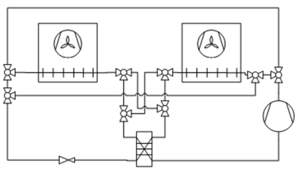
[Domanski et al. 2018]



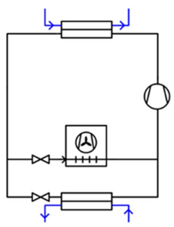
[Bell et al. 2019]

Investigation of Suitable Refrigerants: Household Applications

- A/C System and Heat Pump

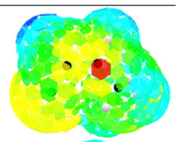
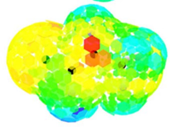


- Dishwasher Heat Pump



Investigation of Suitable Refrigerants: Household Applications

- Validate increased-efficiency model with equations of state
- Identify most-suitable refrigerants with considertion of:
    - o Boundary Conditions
    - o GWP
    - o Heat Exchanger Type
    - o Flammability

IUPAC Name	Struktur	ASHRAE	GWP	Dmol3 COSMO Oberfläche
(Z)-1-fluoroprop-1-ene	CHF=CH-CH3	R1261ze(Z)	1	
(E)-1-fluoroprop-1-ene	CHF=CH-CH3	R1261ze(E)	1	

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Application Examples

Refrigerant and Oil Properties

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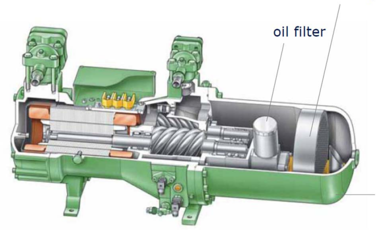
As more working fluids become available…

- **Refrigerant-oil selection can become more challenging**
  - Compressor type
  - Bearings
  - Application (Heat Pumps)
  - Refrigerant solubility in oil (Charge minimization)



[Bitzer]

Fluid Property Characterization

- **Carry out fluid property investigations**
  - Solubility (VLE)
  - Viscosity
  - Surface Tension
  - Thermal Conductivity
  - Foaming Behavior

Fluid Property Characterization

Freezing point

Mixture R744/R170 (45/55)

T_{freeze} = - 68,2 °C

Vapor Pressure and Solubility Gaps

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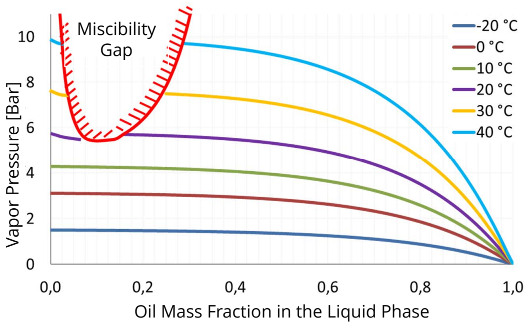
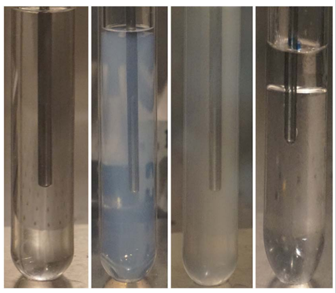
Fluid Property Characterization

Solubility gap and vapor pressure diagrams





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Discussion, Outlook, and Conclusions

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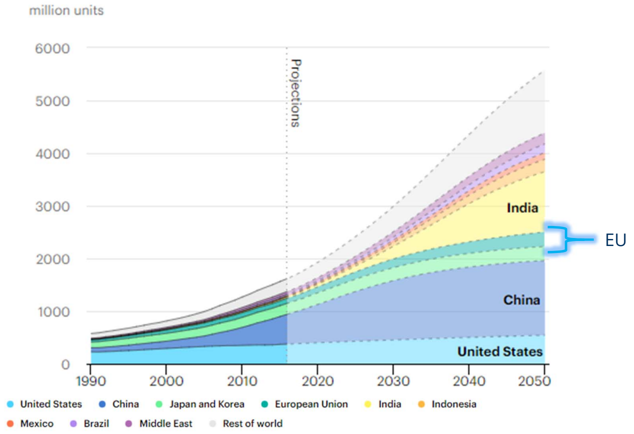
Global Air Conditioner Stock: 1990 - 2050



[IEA]

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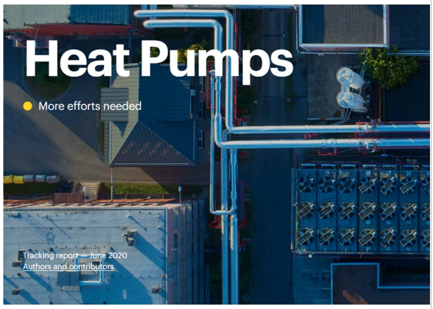
Heat Pump Trends



- **Air to Air: Units sold in the USA**
  - *2015:* 2,3 Million
  - *2019:* 3,1 Million

  + 35%

- **Heat Pump Water Heaters**
  - Global sales: *tripled* since 2010
  - Sales in Europe:
    - 2010: 30,000 Units
    - 2018: 155,000 Units

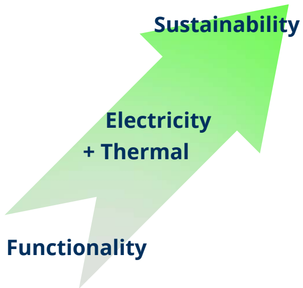
    > 5x

- **Ground-source heat pumps**
  - USA: sales have doubled since 2010
  - Sweden: Highest installation rate per capita globally

[IEA]

Conclusion

Conclusion



- Growing energy demand
- Significant demand for thermal energy
- Decarbonization
- Integrated thermal and electric energy systems

- ➢ Heat pumping and ORC technologies
- ➢ Attention to acceptance of working fluids
- ➢ Cycles modifications and enhancements for an efficient and sustainable application of the working fluids
- ➢ Awareness in Education

Application Examples
Air Conditioning

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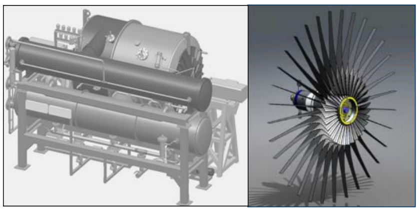
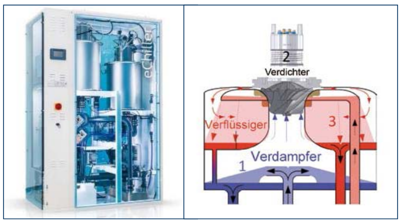
R718 Water Chiller

R718 centrifugal chillers for low temperature lift





800 kW Chiller
[Honke et al. 2015]

35 kW Chiller
With 2 centrifugal stages
[efficient-energy.de]

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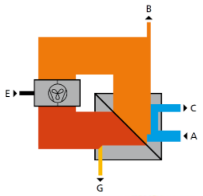
R718 Heat Recovery and Heat Pump

Mechanical vapor compression

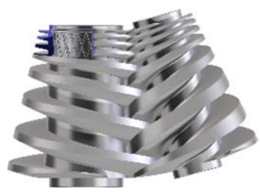


A Einzudampfendes Produkt
B Brüden
C Konzentrat
E Elektrische Energie
G Brüdenkondensat

Rotary piston blower
[Quelle: Kaeser]

Positive displacement compressor for larger temperature lift

- Large pressure ratio
- High discharge temperature



Conical spindel compressor
[Steffens 2017]

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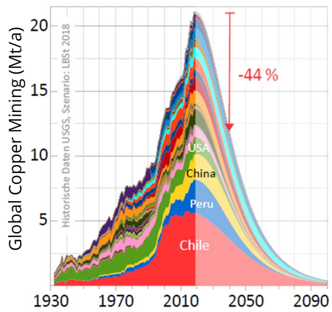
Sustainability Assessment

Energy consumption and global warming effects are only part of a sustainability assessment

- e.g. Limitation of raw material resources

➢ Life Cycle Assessment enables comparison of sustainability

Copper Mining



/DKV, 2017 from „Kritische Metalle in der großen Transformation"; Exner et al., Springer 2016, akt. 2018/

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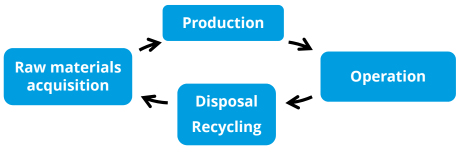
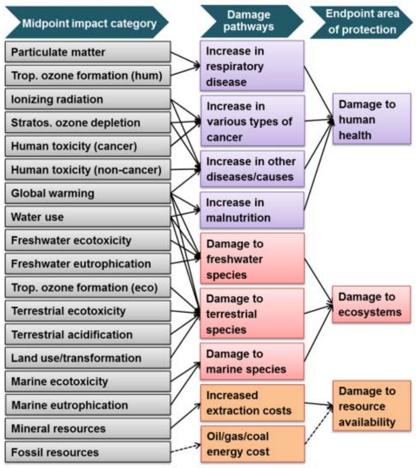
Life Cycle Assessment (LCA)
of products, processes or services

- All material and energy during whole life cycle (ISO 14040 and 14044)



- Environmental impacts incl.:
  - o resource use
  - o human health
  - o ecological consequences
- Impact assessment method (e.g. ReCiPe)



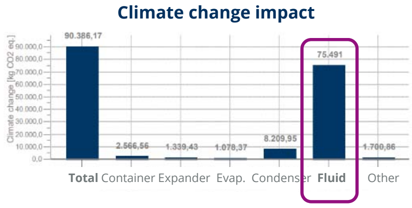
/ReCiPe 2016 v1.1, National Institute for Public Health and the Environment, 2017/

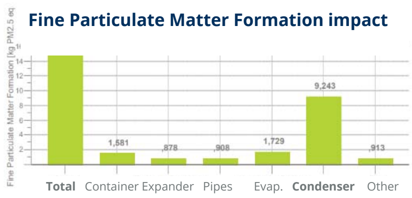
Importance of Life Cycle Assessment
Example of an ORC-plant

LCA of a 100 kW_{el} ORC-plant
air-cooled condenser for waste heat recovery
- Working fluid R245fa causes over 80 % of the CO_2-equiv emissions
- Significant Fine Particulate Matter Formation of condenser caused by aluminum production

If low-GWP fluids are used
- Relative share of CO_2-equiv emissions from system components increase
- Other impact categories gain significance

➢ Increasing importance to consider emissions of components and further impact categories

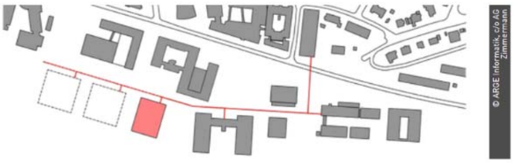




A/C Load Reduction

Data Center
- Direct water cooled computer racks
- e.g.: Lehmann-Zentrum (LZR) at TU Dresden
  1 MW direct water cooled

computer racks



District heating 52 / 35 °C

water for direct cooling 35 °C supply

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A/C Load Reduction

Bio wall

- Filtration and absorption of trace gases and dust by leafs and roots
- Energy saving due to increased recirculation
- Evaporative cooling

/Mietusch R.: Diplomarbeit „Design and Installation of a Biowall Test Bench", Purdue University and TU-Dresden, 2015/

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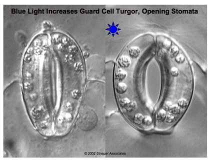
A/C Load Reduction

Plants for shade and evaporative cooling

/Marco Schmidt: Energieeffiziente Gebäudeküh-lung, Paradigmenwechsel durch innovative Wasserkonzepte, UBA-Tagung „Nachhaltige Kälteversorgung in Deutschland", 2013, Dresden/



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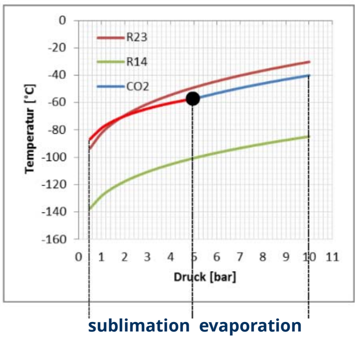
Sublimation of Carbon Dioxide R744

R744 and R23:

- Similar vapor pressure curves
- Above triple point pure R744 would be a good replacement for R23

- Triple point R744:

  T_{tr} = -56,6 °C p_{tr} = 5,18 bar



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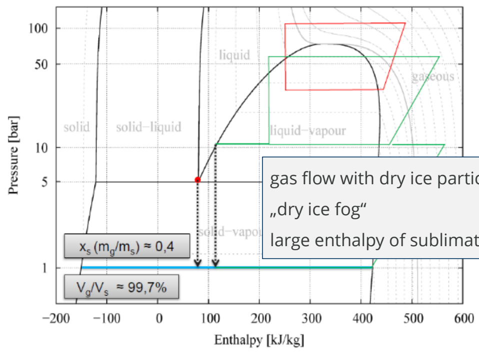
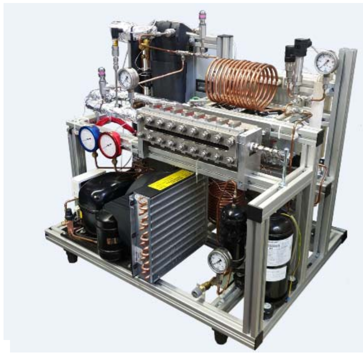
Sublimation of Carbon Dioxide R744



gas flow with dry ice particles
„dry ice fog“
large enthalpy of sublimation



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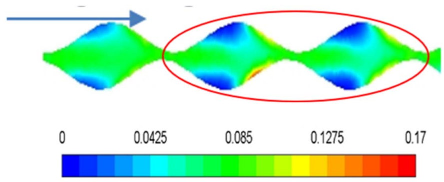
Flammable Refrigerants - Secondary refrigerants

Ice slurry as secondary refrigerant:

Water with additive e.g. ethanol or salt (sea water)
- (+) large specific capacity due to melting enthalpy
- (+) low pressure
- (+) cold storage
- (-) risk of separation
- (-) monitoring of concentration needed
- (-) **risk: blocking due to agglomeration of particles**

Modelling of ice slurry in plate HX
- Prediction of blocking
  - ➢ Design change



/Shaimaa Hefny Badawi: DKV - Deutsche Kälte- und Klimatagung 2020/

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72

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Thermal Energy

Recovery of conversion losses (waste heat , waste cold) and **environmental heat**

Utilization of renewable energy:

- Refrigeration and A/C
- Heat pumps
- Hybrid use of heating and cooling
- High temperature heat pumps (including process heat > 150 °C)

Heat Pumping Machines

Thermodynamic Machines

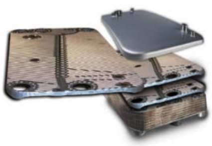
Power generation:

- CRC and ORC machines

Flammable Refrigerants - Compact Heat Exchanger

Integrated evaporator, condenser and internal heat exchanger

Propane Chiller: Charge 2,2 kg R290, ca. 45 g/kW



Retain?

/Multichannel AB/

/Futron /

Application Examples
Energy Storage

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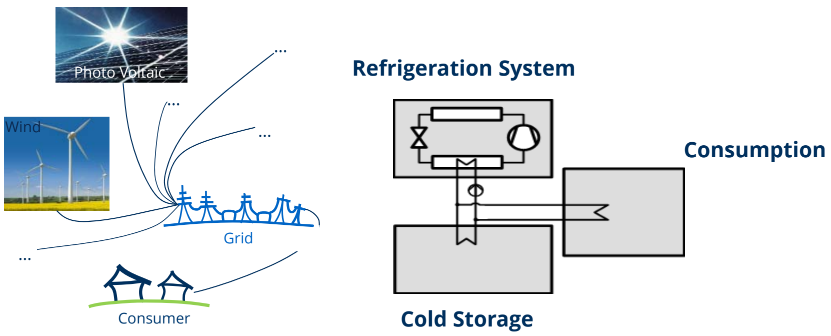
Energy Storage – Refrigeration, A/C and Heat Pumps



Temporal decoupling of cooling generation and cooling demand

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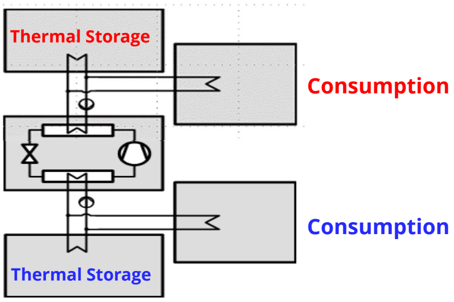
Energy Storage – Refrigeration, A/C and Heat Pumps

Hybrid system



Motivation:

- Simple
- Known
- Decentralized
- Environmentally begin

2 sides: warm and cold thermal storage

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A new flow modulation technique for R744 two-phase ejectors

7th International Symposium on Advances in Refrigeration and Heat Pump Technology

4 October 2021

Assoc. Prof. Paride Gullo, *Ph.D.*[1,2]
[1] SDU Sønderborg, Dept. of Mechanical and Electrical Engineering
[2] DTU, Dept. of Mechanical Engineering

DTU Technical University of Denmark

SDU University of Southern Denmark

Danfoss

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Agenda

→ Introduction

→ Available flow modulation techniques

→ New flow modulation technique

→ Conclusions

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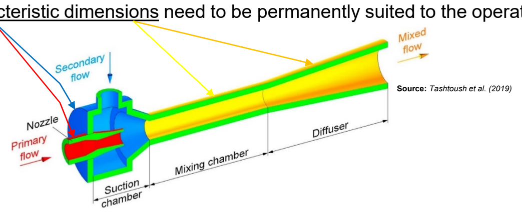
Introduction

→ R744 two-phase ejectors lead to COP improvements by up to 30 % at **DESIGN conditions**

→ Need for an effective flow modulation of the ejector

- Ejector-equipped R744 system performance dramatically penalized at off-design operations
  - 4 ejector characteristic dimensions need to be permanently suited to the operating conditions



  - Need to effectively control high pressure to maximize COP in R744 systems
    - e.g. -3 % to -17 % in COP as $P_{gas\ cooler} = P_{gas\ cooler,optimal} \pm 5$ bar

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Flow modulation techniques

→ Needle-based ejector

→ Multi-ejector concept

→ Vortex-based ejector

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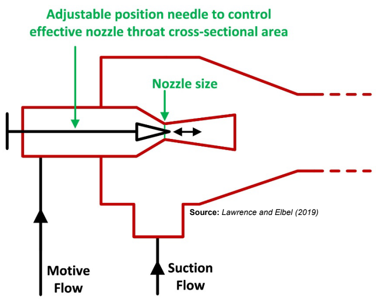
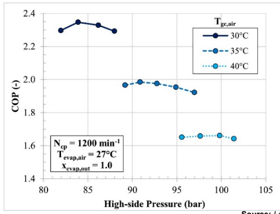
Flow modulation techniques

→ Needle-based ejector



Source: *Lawrence and Elbel (2019)*



Source: *Lawrence and Elbel (2019)*

COP improvement gained by high-side pressure control of ejector cycle (ejector cycle at optimum high-side pressure compared to ejector cycle with no active control) and maximum ejector efficiency (observed with no use of needle).

N_{cp} (min^{-1})	$T_{gc,air}$ (°C)	COP improvement	$\eta_{ejec, max}$
900	35	3.8%	16.6%
1200	30	2.3%	25.9%
1200	35	1.0%	22.8%
1200	40	0.6%	21.3%
1500	35	1.4%	27.2%
1800	35	0.4%	25.8%

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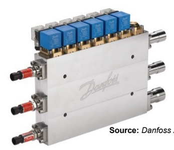
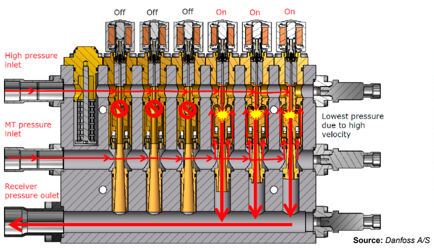
Flow modulation techniques(2)

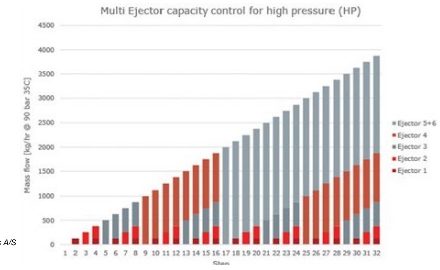
→ Multi-ejector concept

- Low pressure lift
  - 40 kW to 150 kW
  - No parallel compression
  - 3 bar/63% @ 23°C
  - 7 bar/50% @ 36°C
- High pressure lift
  - 100 kW to 300 kW
  - Parallel compression
  - 6 bar/25% @ 23°C
  - 11 bar/25% @ 36°C


Source: *Danfoss A/S*



Source: *Danfoss A/S*



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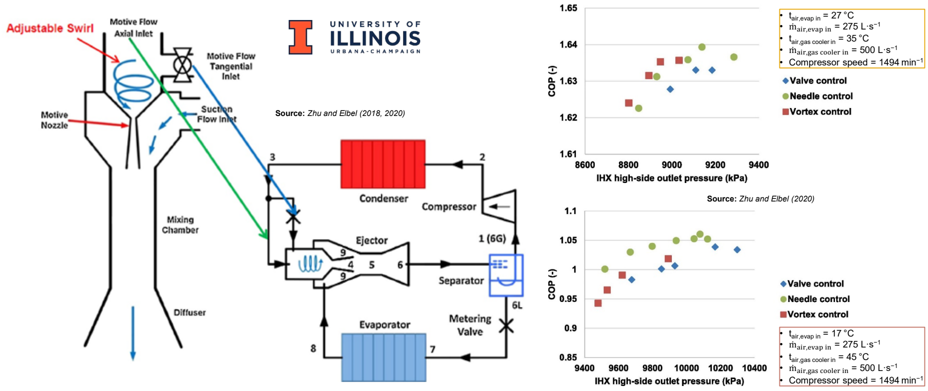
Flow modulation techniques(3)

→ Vortex-based ejector



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Flow modulation techniques(4)

Flow modulation technique	Affordability	Simplicity	Clogging invulnerability	Absence of size/application constraints	Status
Needle	NO	NO	NO	YES	Lab for small systems Used in supermarkets
Multi-ejector	NO (for small systems)	NO	YES	NO	Used (mainly) in supermarkets
Vortex	YES	YES	YES	YES	Lab

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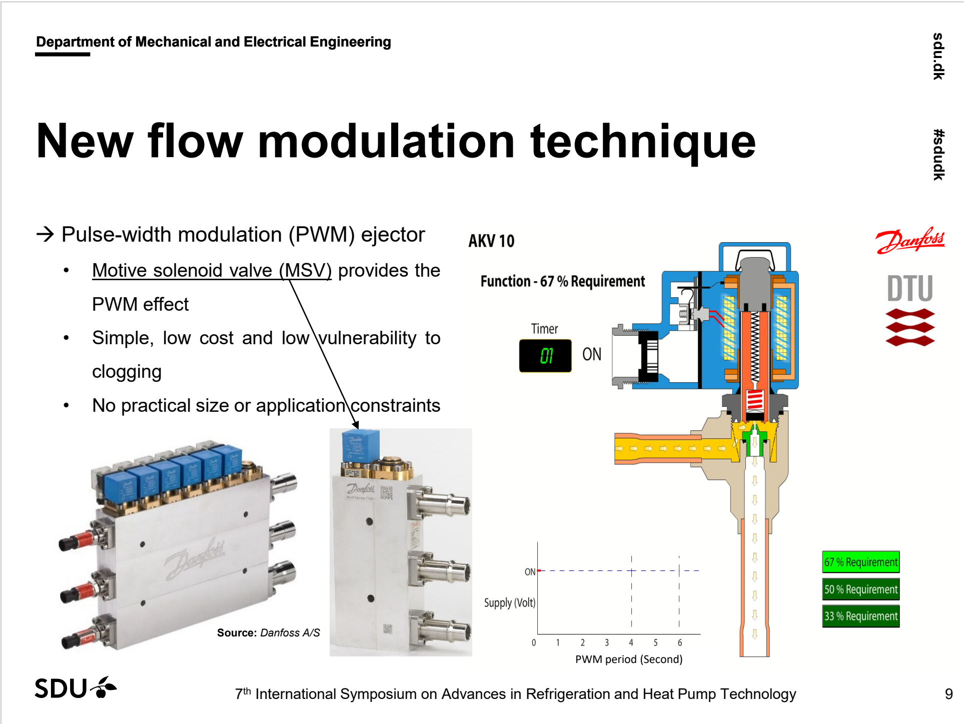

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New flow modulation technique
→ Pulse-width modulation (PWM) ejector
• Motive solenoid valve (MSV) provides the PWM effect
• Simple, low cost and low vulnerability to clogging
• No practical size or application constraints
Source: Danfoss A/S
AKV 10
Function - 67 % Requirement
Timer
01
ON
Supply (Volt)
PWM period (Second)
67 % Requirement
50 % Requirement
33 % Requirement
DTU
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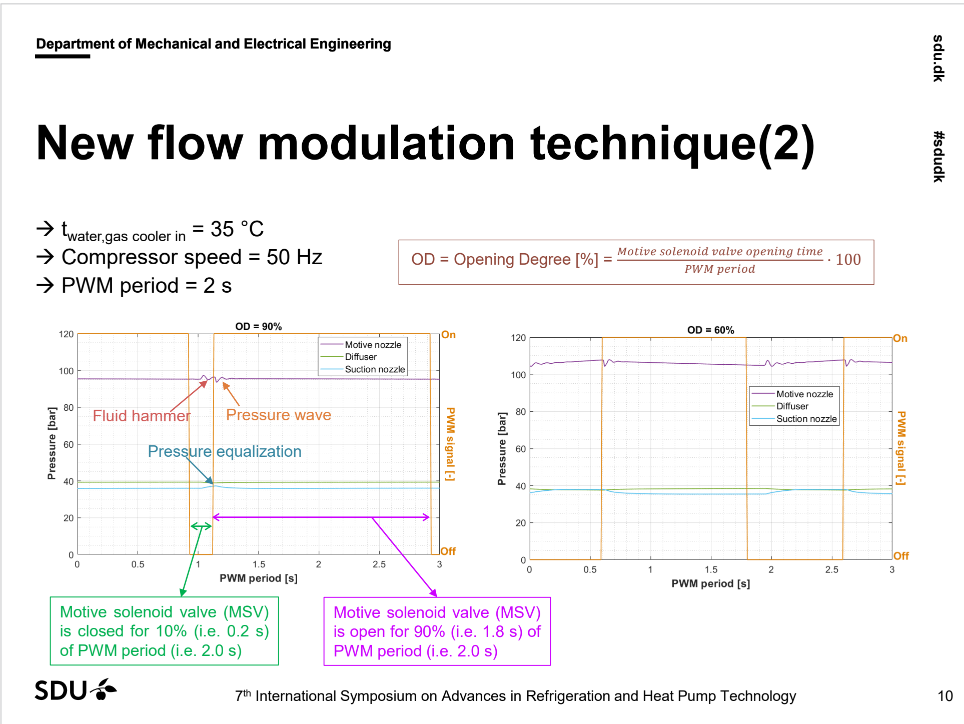

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New flow modulation technique(2)
→ t water,gas cooler in = 35 °C
→ Compressor speed = 50 Hz
→ PWM period = 2 s
OD = Opening Degree [%] = Motive solenoid valve opening time / PWM period · 100
OD = 90%
Motive nozzle
Diffuser
Suction nozzle
Fluid hammer
Pressure wave
Pressure equalization
Pressure [bar]
PWM signal [-]
PWM period [s]
On
Off
OD = 60%
Motive solenoid valve (MSV) is closed for 10% (i.e. 0.2 s) of PWM period (i.e. 2.0 s)
Motive solenoid valve (MSV) is open for 90% (i.e. 1.8 s) of PWM period (i.e. 2.0 s)
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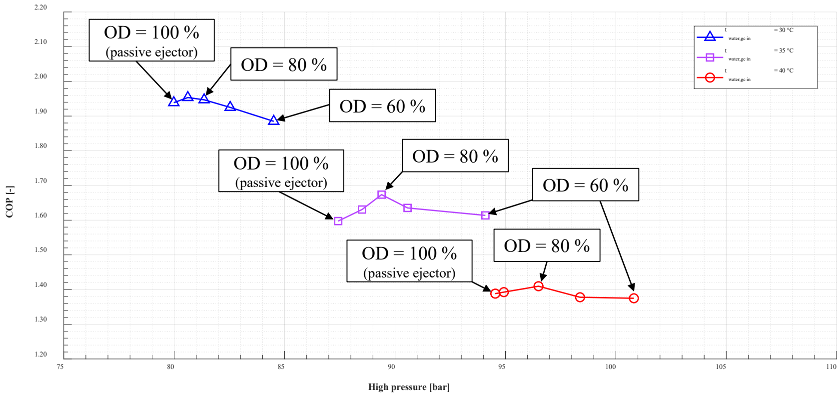
New flow modulation technique(3)

→ Compressor speed = 50 Hz, $t_{eg,evap\ in}$ = 5 °C, $\Delta T_{superheating}$ = 8 K, PWM period = 2 s, no mufflers



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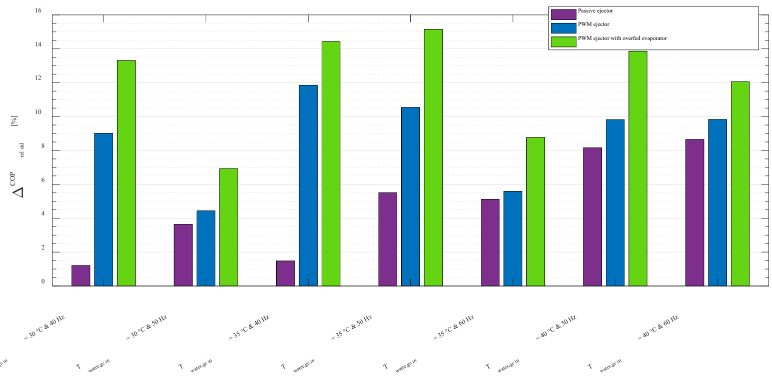
New flow modulation technique(4)

→ Optimal operation conditions, $t_{eg,evap\ in}$ = 5 °C, $\Delta T_{superheating}$ = 8 K for dry-expansion evaporators, PWM period = 2 s, no mufflers



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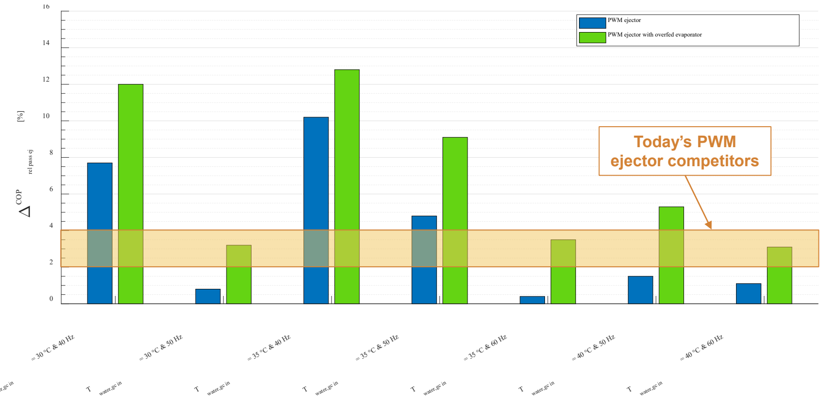
New flow modulation technique(5)

→ Optimal operation conditions, $t_{eg,evap\ in}$ = 5 °C, $\Delta T_{superheating}$ = 8 K for dry-expansion evaporators, PWM period = 2 s



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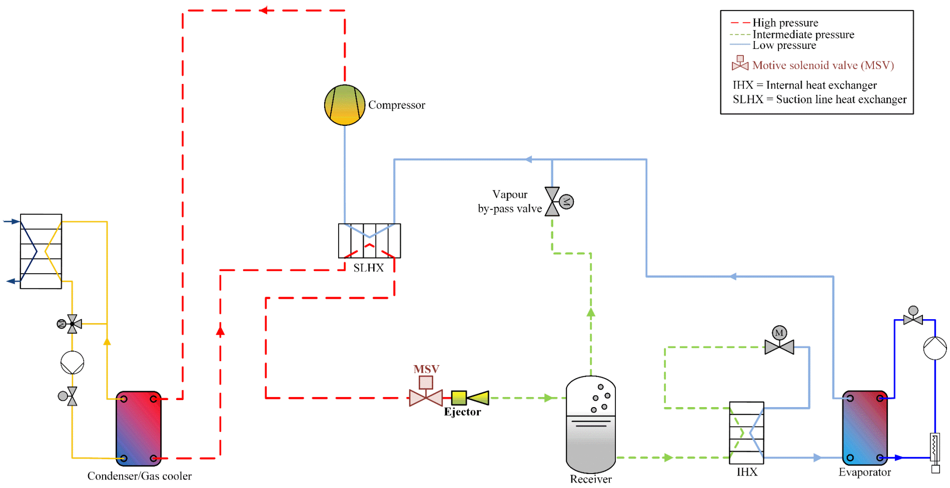
New flow modulation technique(6)



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New flow modulation technique(7)

→ $\Delta T_{subcooling}$ = 2 K, $t_{eg,evap\ in}$ = 5 °C, $\Delta T_{superheating}$ = 8 K, PWM period = 2 s

	High pressure valve	**PWM motive nozzle**	**High pressure valve**	**PWM motive nozzle**
Operating condition	P_{gc} [bar]	P_{gc} [bar]	COP [-]	COP [-]
$t_{water,gc\ in}$ = 15.0 °C @ 40 Hz	60.77	61.15	3.28	3.29
$t_{water,gc\ in}$ = 15.0 °C @ 50 Hz	61.87	62.40	2.87	2.89
$t_{water,gc\ in}$ = 15.0 °C @ 60 Hz	62.87	63.24	2.62	2.61
$t_{water,gc\ in}$ = 17.5 °C @ 50 Hz	64.79	65.05	2.68	2.67
$t_{water,gc\ in}$ = 20.0 °C @ 50 Hz	67.11	67.71	2.46	2.53

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Conclusions

→ PWM ejector modulates flow effectively, regardless compressor speed and heat sink temperature

→ COP enhancements much higher than today's competitors

→ PWM ejector motive nozzle offers same effectiveness as a conventional high pressure valve in subcritical regime

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→ Madsen, K.B., Kriezi, E.E., 2018. *Financial aspects of ejector solutions in supermarket and smaller industrial systems*. In: Proceedings of the 13^{th} IIR-Gustav Lorentzen Conference on Natural Refrigerants, 18^{th} - 20^{th} June; Valencia, Spain. ID: 1403.
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→ Zhu, J., Elbel, S., 2018. *Vortex control for motive flow rate modulation of transcritical R744 ejector systems*. In: Proceedings of the 13^{th} IIR-Gustav Lorentzen Conference on Natural Refrigerants, 18^{th} - 20^{th} June; Valencia, Spain. ID: 1290.

SDU

7^{th} International Symposium on Advances in Refrigeration and Heat Pump Technology

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Second generation solar direct drive vaccine cooler

EUDP project on photovoltaic refrigeration

Ivan Katić
Energy & Climate Division
2021-10-04

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Outline

- SDD basics
- Modeling and simulation
- Product development
- Laboratory measurements
- Results

Participants
- Vestfrost Solutions
- SECOP
- DTU MEK
- Teknologisk Institut

Supported by EUDP

EUDP

The Energy Technology Development and Demonstration Programme

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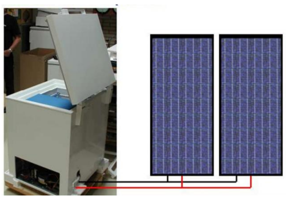
Solar energy for refrigeration- not a new idea

- Solar thermal (absorption cooler)
- Solar PV with battery storage and optional inverter
- Solar PV direct drive (SDD)



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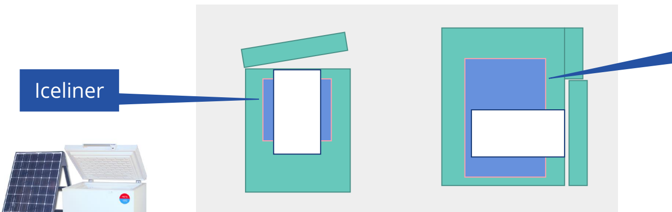
State of the art: Two main principles



- 40 SDD vaccine coolers approved by WHO.
- One of the fastest growing technologies in the vaccine cold chain.

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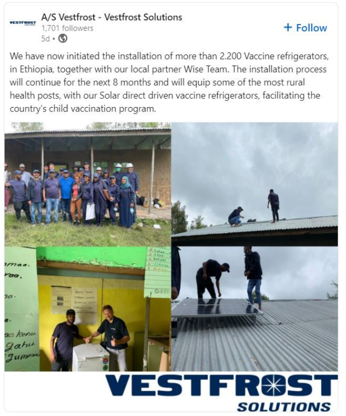
SolarChill® The ultimate solution?

Thermal storage (ice)
No battery (no lead)
Natural refrigerant
No harmful materials



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SDD challenges

=

?

- Limited solar power for compressor start
- No control during night (no battery)
- The most used SDD compliant compressor in the market is very old and not energy efficient. Furthermore, its cooling capacity is very limited.
- WHO has reports from the field indicating insufficient temperature control, in particular risk of vaccine freezing
- Condensation and soaking of vaccine packages is sometimes a problem
- Even though PV panels has become cheaper, a reduction of size could lower total system costs and installation works

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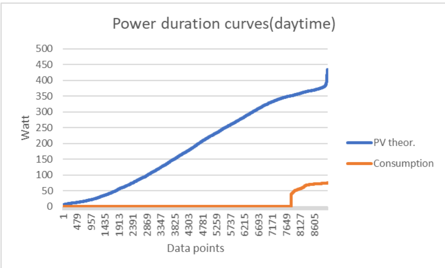
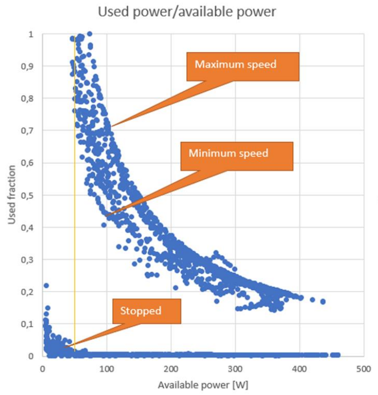
SolarChill® GEF Project: Observations from field test

- Remote monitoring of 5 different brands in Colombia, Kenya and eSwatini
- Power consumption: Lot of surplus power!





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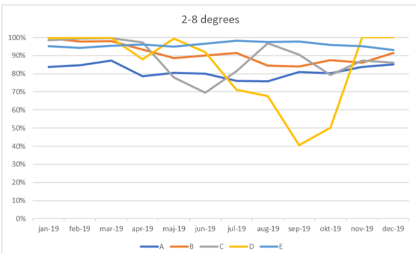
Temperature data



	Type A	Type B	Type C	Type D	Type E
< 0°C	1,2%	0,0%	0,0%	0,0%	0,0%
< 2°C	16,1%	0,5%	8,7%	0,1%	3,8%
OK	82,5%	91,0%	88,6%	84,0%	95,9%
> 8°C	2,4%	8,5%	2,7%	15,9%	0,3%
> 10°C	1,2%	2,4%	0,1%	2,8%	0,2%

- Temperature is not always within 2-8 °C
- Risk of vaccine freezing!

Deviations due to:

- poor thermostat
- uncontrollable internal heat flow
- ice bank not frozen
- leakage of refrigerant

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EUDP Project tasks

PRODUCT

VLS 054A SDD

SOLAR DIRECT DRIVEN REFRIGERATOR

The integrated ice bank technology with increased thermal energy storage provides self controlling and reliable temperatures in the area of +2°C to +8°C rated according to highest climate zone within ambient temperature area from +5°C to +43°C.

Solar panels are connected plug & play directly to the appliances.

The junction box further from safeguard the electrical parts, aeses services as well as maintenance on the appiance. In addition the appliance now is supplied with an appliance socket.

SPECIFICATIONS

Gross volume, litres (cu. ft.)	108 (3.81)
Net volume, litres (cu. ft.)	55.5 (1.95)
Temperature range (43°C AMB)	+2° to +8°C
Autonomy, hours	72.4
Hold-over time, hours	78.2
Refrigerant	R600a
Freeze protection, grade	A
Climate class	T
Min. solar radiation, kWh/m2/day	3.5
Voltage, V Dc	12

WHO SPECIFICATIONS

- Vestfrost Solutions: Improve existing cabinet
  - Bigger ice storage, longer holdover time
  - Improved thermostat control, eliminate freezing risk
- DTU: Simulation of design options and control strategies
- SECOP: Selection and testing of a new compressor platform and develop SDD controller
  - More than 20% increased cooling capacity
  - Improved dynamic range 1:3
  - Power converter adapted to common PV modules
- DTI: Test of prototypes in the laboratory

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Most important challenge: Temperature control

- In cold surroundings there is a risk that the compressor does not run enough to ensure freezing and buildup of an icelayer. The water may also be subcooled without forming any ice.
- This results in much higher temperature fluctuations than with an ice/water mixture.
- In hot surroundings the compressor is running a lot and will likely freeze the entire iceliner by end of a sunny day. It is critical that the compressor stops as soon as the ice temperature is slightly negative.
- Vaccine freezing must be avoided! (Ambient temperature 5-43°C)

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Simulation results

DTU MEK
Jonas Kjær Jensen

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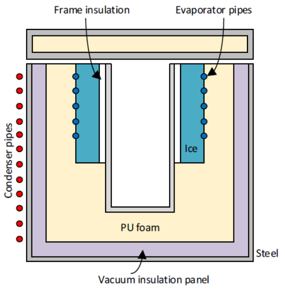
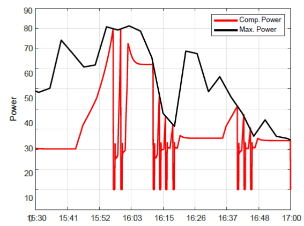
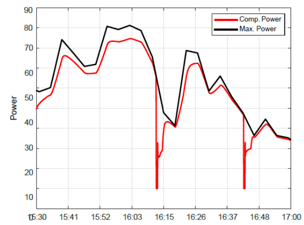
Cabinet layout

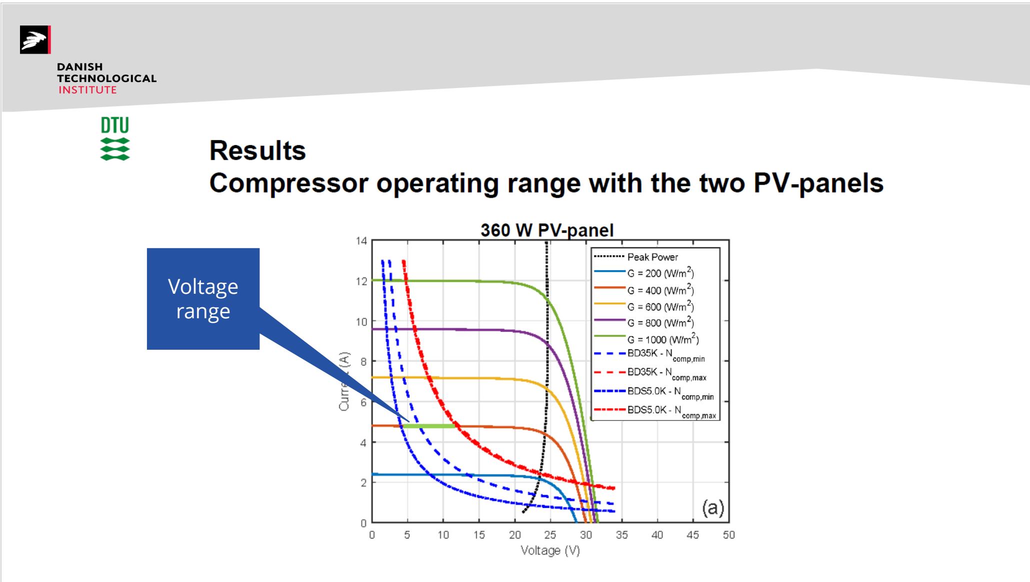


Old AEO controller (Adative Energy Optimizer)



Constant voltage controller

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DTU
Results
Compressor operating range with the two PV-panels
Voltage range
360 W PV-panel
Peak Power
G = 200 (W/m2)
G = 400 (W/m2)
G = 600 (W/m2)
G = 800 (W/m2)
G = 1000 (W/m2)
BD35K - Ncomp,min
BD35K - Ncomp,max
BDS5.0K - Ncomp,min
BDS5.0K - Ncomp,max
(a)
Voltage (V)


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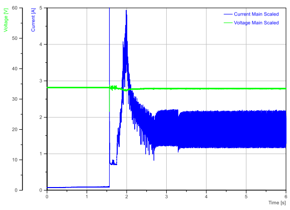
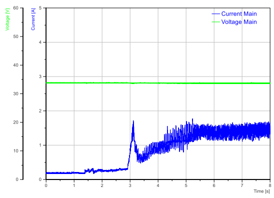
Laboratory results
SECOP & DTI

SECOP



Electronics

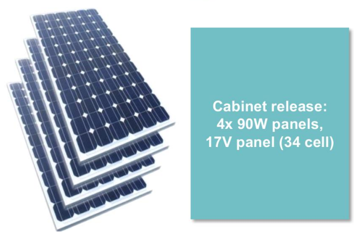
- Lower PV price per Watt: Voltage adapted to most common PV module market (72 cells)
- Improved power electronics for MPP tracking and soft start

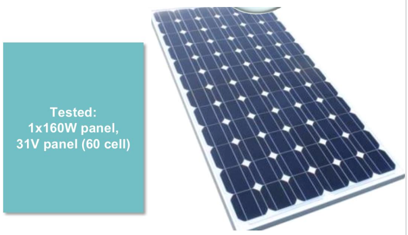


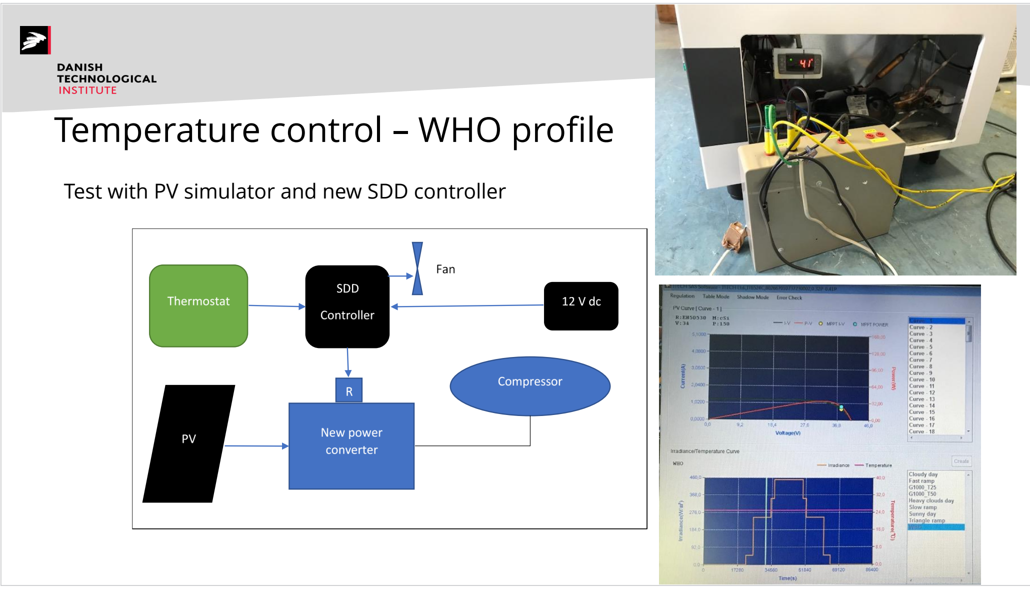
SECOP

Test of a compressor type with reduced power demand:

4*90W solar panels
can be substituted by
1* 160W panel
=>cheaper and simpler installation



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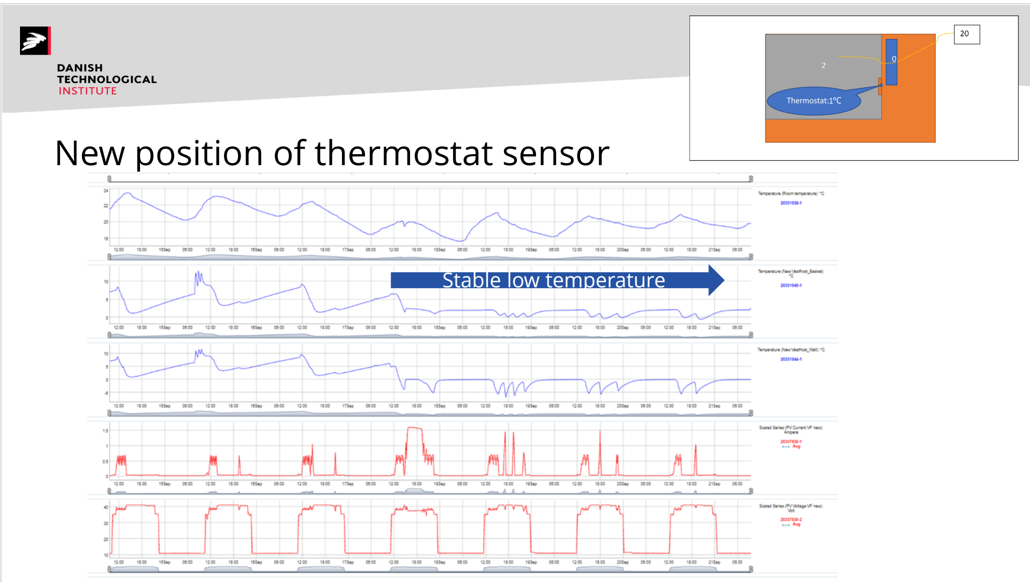
Temperature control – WHO profile
Test with PV simulator and new SDD controller
Thermostat
SDD
Controller
Fan
12 V dc
Compressor
R
PV
New power
converter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New position of thermostat sensor
20
2
0
Thermostat:1°C
Stable low temperature

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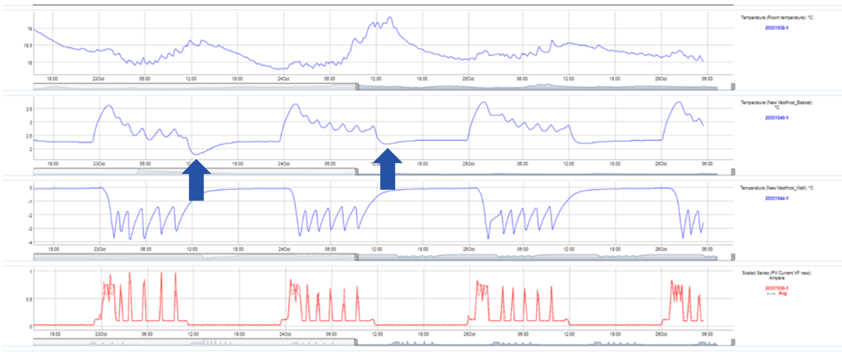
Electric heater (12W): Higher minimum temperature



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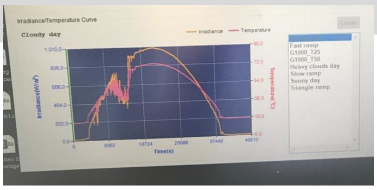
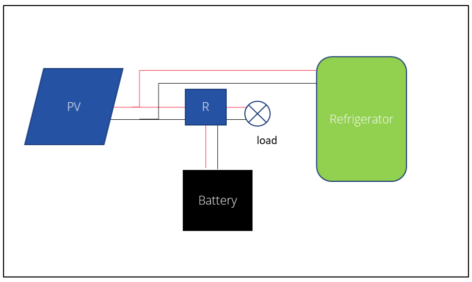
Energy harvesting experiments

- Dynamic simulation of a PV module
- MPP charge controller + lamp load
- Basic operation not affected ☺



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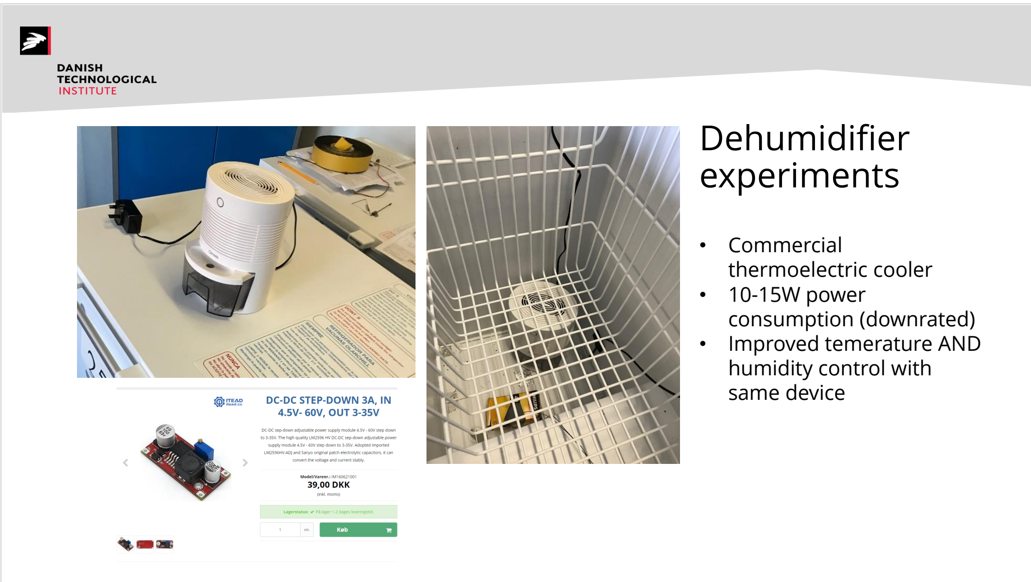
Subcooling experiments
Test of additives known from litterature
Open or sealed containers
Partly inconclusive results
Freezing in open cups
Granulate
Hexanol
Pentanol
Pure water
Freezing in closed bags
Bag temperature °C
Seconds
Granulate
Hexanol
Pentanol
Pure water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Dehumidifier experiments
Commercial thermoelectric cooler
10-15W power consumption (downrated)
Improved temerature AND humidity control with same device
DC-DC STEP-DOWN 3A, IN 4.5V- 60V, OUT 3-35V
39,00 DKK

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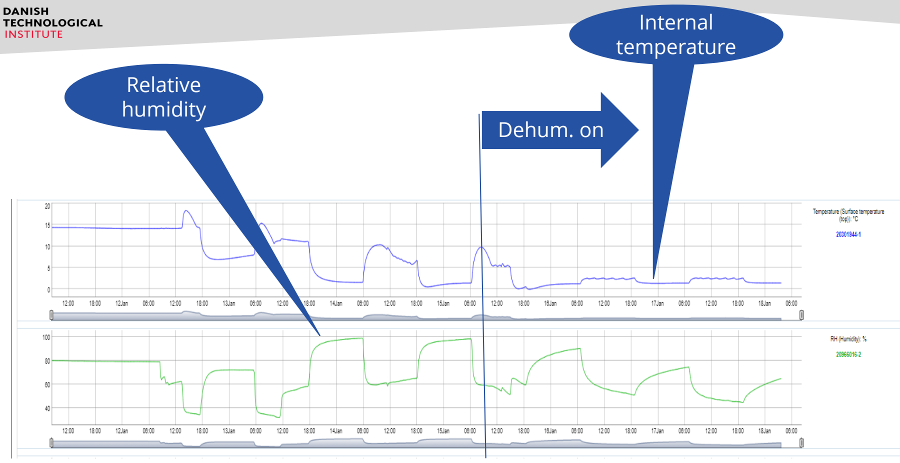

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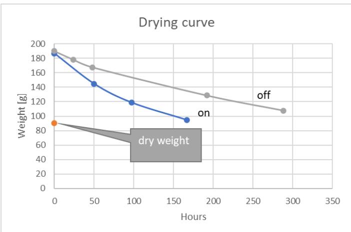
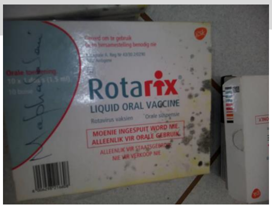
Dehumidifier efficiency

- Drying rate measurement
- Water saturated packaging material





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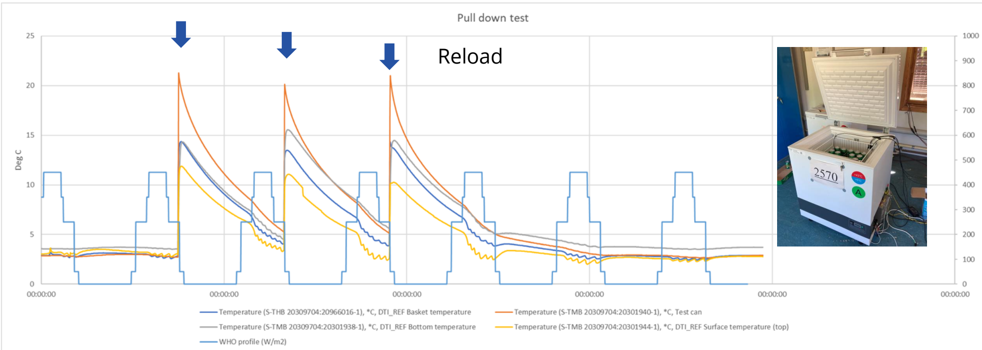
Test of cooling capacity (51 x 0.33 L/day)

150 Wp PV module



S

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Results achieved by SECOP

SECOP BD-Nano50K Direct Drive compressor

- Cooling capacity increased from 36W to 50.8W (+41%) @-25/55 CECOMAF
- COP increase from 0.87 W/W to 1.19 W/W (+37%)
- Wider dynamic range 1:3
  - → FAIL not possible to reduce min speed with this small compressor. (from 1 : 1,75 to 1 : 1.96 only)
- Environmentally friendly: Using R600a
- Production of new compressor starts Nov. 2021
- Production of new SDD control starts 2022

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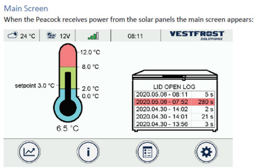
Results achieved by VestfrostSolutions

- Longer hold-over time 73 -> 89 h
- Sophisticated temperature controller :
  - Ice bank sensor controls compressor
  - Surface sensor controls heater
  - Additional surface sensor for freeze protection controller breaks compressor circuit
- New remote monitoring device “EMS” connected to GSM mobile phone network
- Prepared for secondary power loads, e.g. phone charging and lights
- Approved according to the WHO specifications
- The new products will be marketed later on in 2021



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Summary

- Most project objectives have been fulfilled:
  - Increased capacity
  - Higher efficiency
  - Better temperature control
- Vestfrost has strengthened their competivity in the medical SDD segment
- Still need for bigger and cheaper models for households and commercial applications
- Integration with solar PV/battery (Solar home systems)?


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Thank you for your attention!
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www.dti.dk
https://www.solarchill.org/
https://energiforskning.dk/projekter/ny-generation-solcelledrevne-koeleskabe-med-is-lager

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Danske Koledage | TEKNOLOGISK INSTITUT | DTU Mekanik Institut for Mekanisk Teknologi

Køle- og Varmepumpeforum 2021

7th International Symposium on Advances in Refrigeration and Heat Pump Technology

High Temperature Heat Pump System based on water vapor

Hans Madsbøll

hm@teknologisk.dk, +45 7220 1263

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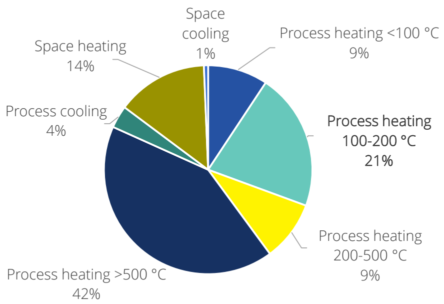
High temperature heat pumps - applications

Energy demand for heating and cooling in industry in EU28 in 2015



https://heatroadmap.eu/heating-and-cooling-energy-demand-profiles/

- Large heat demand between 100 °C - 200 °C
- Relevant processes:
  - Heating
  - Baking/Cooking
  - Drying
  - Evaporation
  - Steam production

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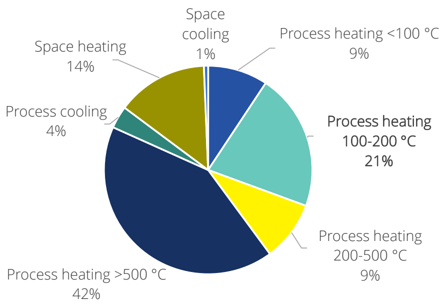
High temperature heat pumps - structure

Energy demand for heating and cooling in industry in EU28 in 2015



https://heatroadmap.eu/heating-and-cooling-energy-demand-profiles/

- Background and motivation for steam as ‘refrigerant’
- ELFORSK project on spindle compressor HP with 230°C supply temperature
- Innobooster project with turbo compressor for 80/110°C operation
- SuPrHeat project – demonstrate 500 kW units

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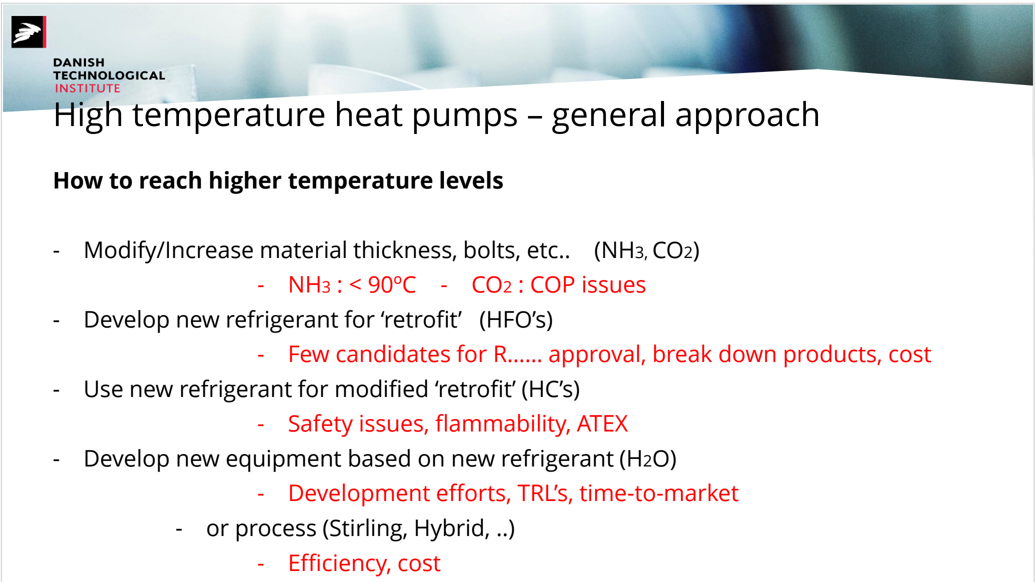
High temperature heat pumps – general approach

How to reach higher temperature levels

- Modify/increase material thickness, bolts, etc.. (NH_3, CO_2)
- Develop new refrigerant for ‘retrofit’ (HFO’s)
- Use new refrigerant for modified ‘retrofit’ (HC’s)
- Develop new equipment based on new refrigerant (H_2O)
    - or process (Stirling, Hybrid, ..)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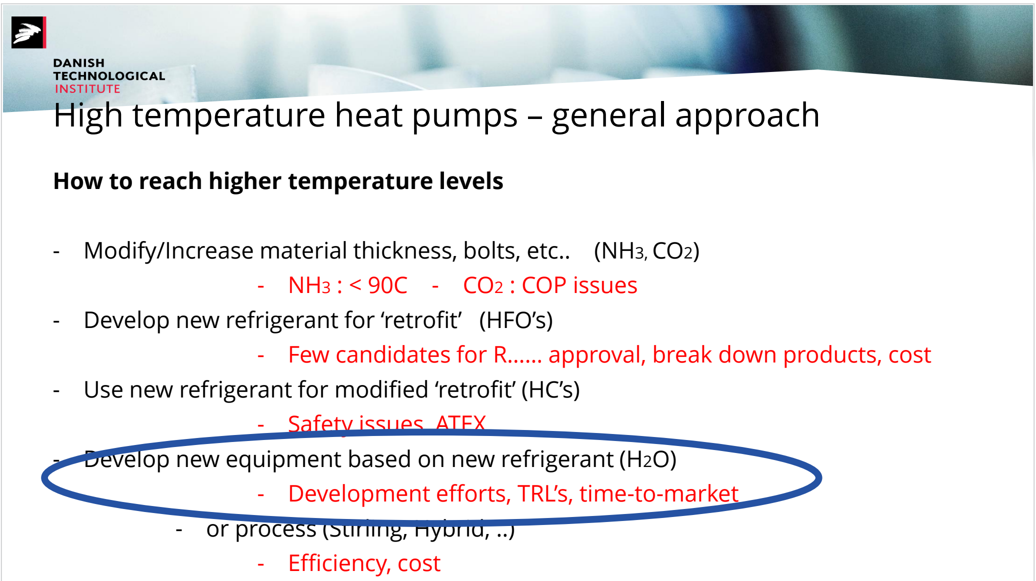
High temperature heat pumps – general approach
How to reach higher temperature levels
- Modify/Increase material thickness, bolts, etc.. (NH_3, CO_2)
- NH_3 : < 90°C - CO_2 : COP issues
- Develop new refrigerant for 'retrofit' (HFO's)
- Few candidates for R...... approval, break down products, cost
- Use new refrigerant for modified 'retrofit' (HC's)
- Safety issues, flammability, ATEX
- Develop new equipment based on new refrigerant (H_2O)
- Development efforts, TRL's, time-to-market
- or process (Stirling, Hybrid, ..)
- Efficiency, cost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High temperature heat pumps – general approach
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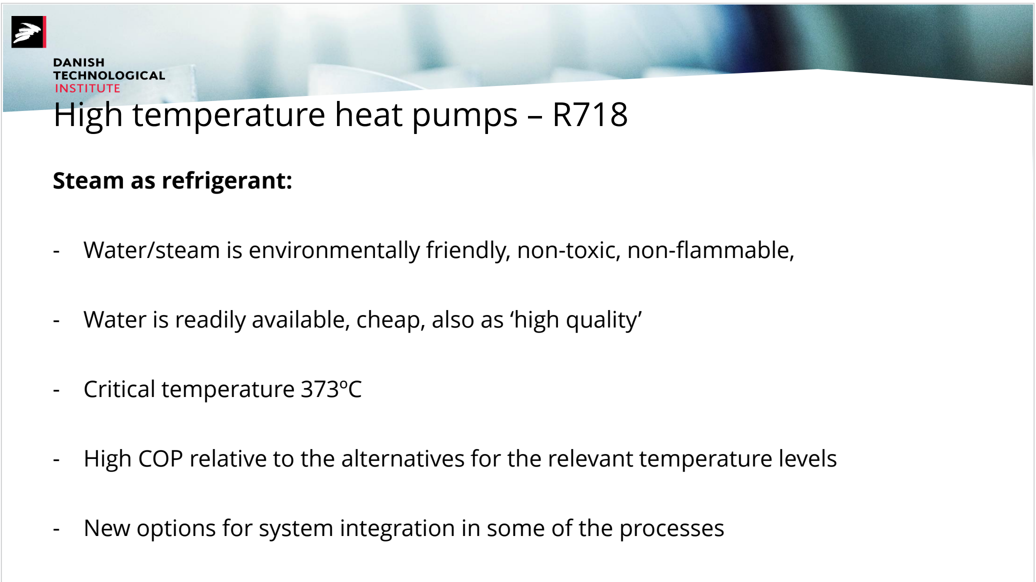
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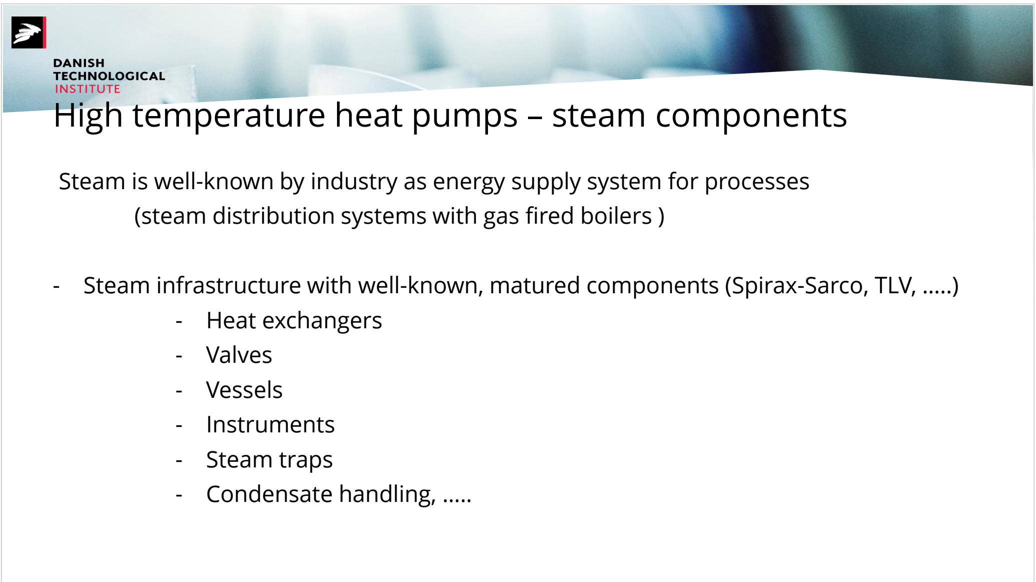
High temperature heat pumps – R718
Steam as refrigerant:
- Water/steam is environmentally friendly, non-toxic, non-flammable,
- Water is readily available, cheap, also as 'high quality'
- Critical temperature 373ºC
- High COP relative to the alternatives for the relevant temperature levels
- New options for system integration in some of the processes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High temperature heat pumps – steam components
Steam is well-known by industry as energy supply system for processes
(steam distribution systems with gas fired boilers)
- Steam infrastructure with well-known, matured components (Spirax-Sarco, TLV, …..)
- Heat exchangers
- Valves
- Vessels
- Instruments
- Steam traps
- Condensate handling, …..

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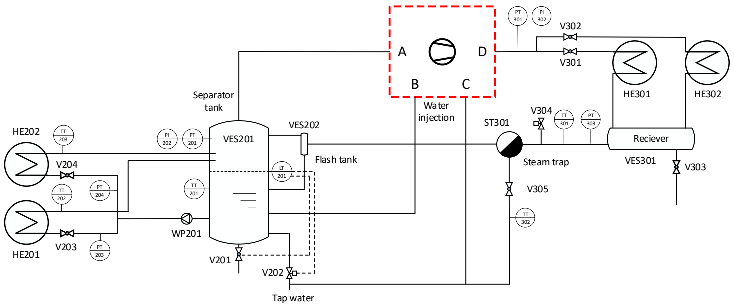
High temperature heat pumps – steam components



Example of unit layout

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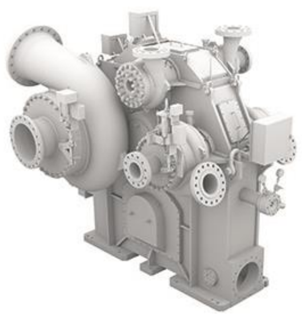
High temperature heat pumps – steam compressors



Issues with existing compressors: Capacity, cost, efficiency, temperature lift, ..

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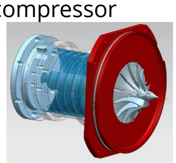
High temperature heat pumps – compressor development

- High temperature heat pump for tunnel oven and spray drying (ELFORSK)
  Spindle compressor
  105/230ºC

Senius (Flexmatic)
Hamburg Vacuum,
CSTechcom,
Sanovo, DTI (PM)

- High temperature heat pump (Innobooster)
  Direct drive turbo compressor
  80/110ºC



CSTechcom (DTI subsupplier)

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High temperature heat pumps – compressor development

- High temperature heat pump for tunnel oven and spray drying (ELFORSK 2020)

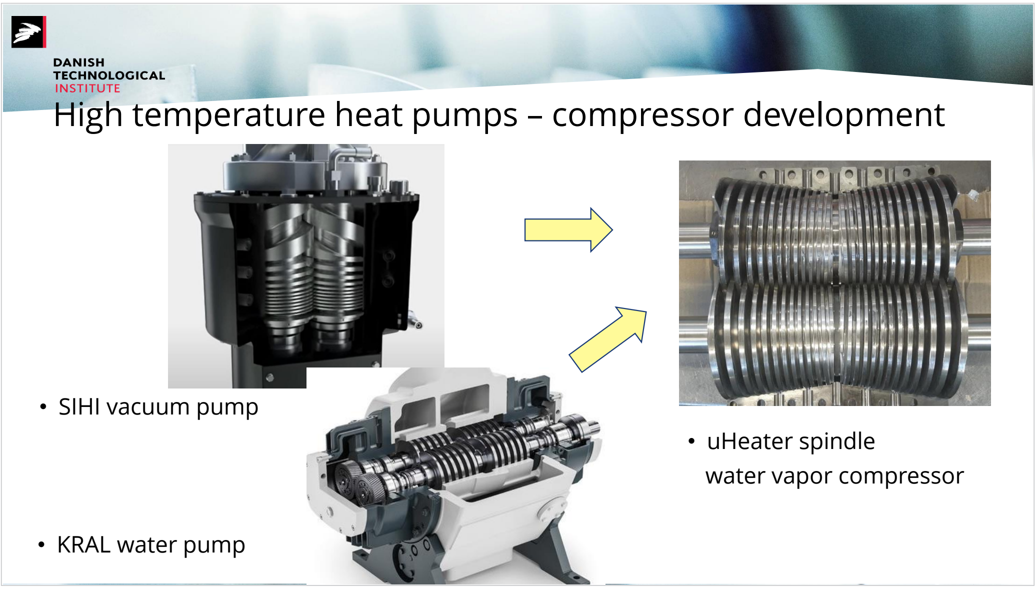
Senius tunnel oven

Capacity – 150 kW,
Stand alone unit

Supply temperature
180 – 250ºC

Source temperature
60 – 120ºC

COP – 2 to 3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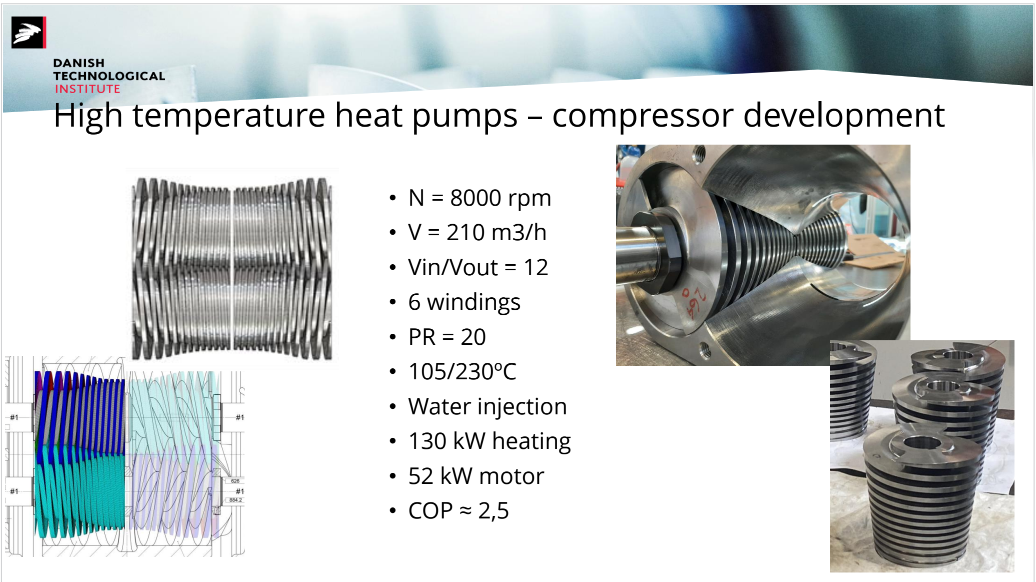
High temperature heat pumps – compressor development
• SIHI vacuum pump
• KRAL water pump
• uHeater spindle
water vapor compressor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High temperature heat pumps – compressor development
• N = 8000 rpm
• V = 210 m3/h
• Vin/Vout = 12
• 6 windings
• PR = 20
• 105/230°C
• Water injection
• 130 kW heating
• 52 kW motor
• COP ≈ 2,5

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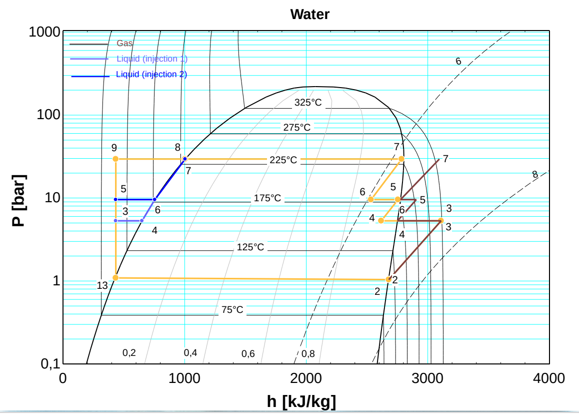
High temperature heat pumps – compressor development



- Water injection at two (four) locations
- ‘wet compression’ to reduce discharge temperature and improve efficiency

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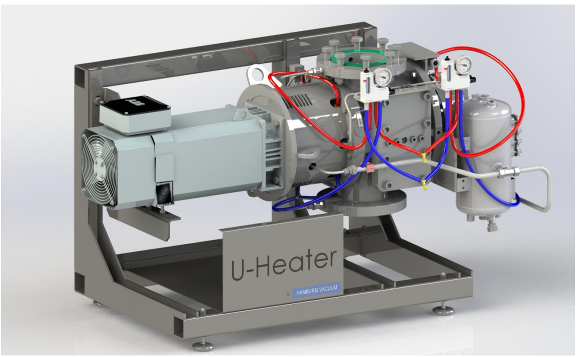
High temperature heat pumps – compressor development



- Assembled at KRAL (Austria) – proof of concept test at Senius test rig November

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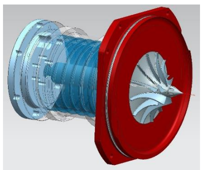
High temperature heat pumps – compressor development

- Direct drive turbo compressor – CSTechcom Innobooster project



Capacity – 200 kW
Supply temperature - 110ºC
Source temperature - 80ºC
N = 95 krpm
PR ≈ 3.0
Motor – 22 kW
COP – 8 to 9
DTI aerodynamic design

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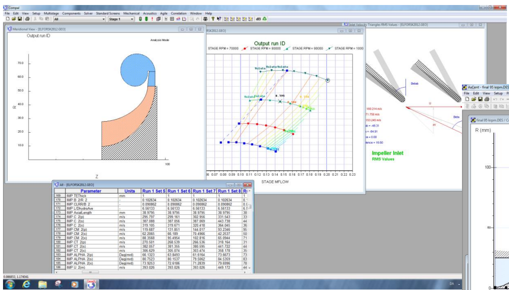
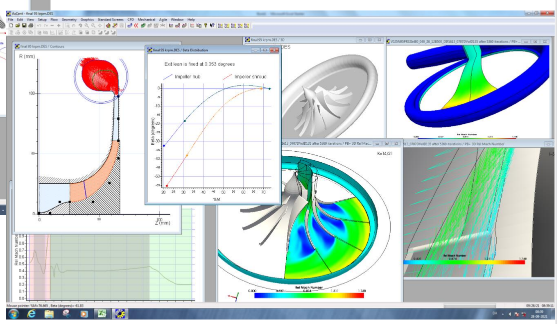
High temperature heat pumps – compressor design





Design software form Concepts NREC at DTI,
1D for overall design and performance prediction,
3D for detailed geometry design and optimization

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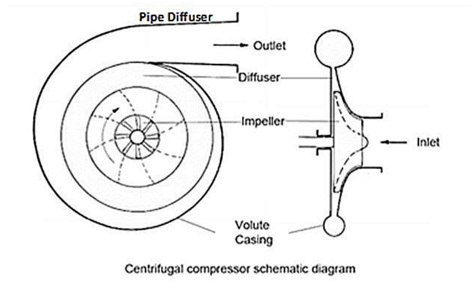
High temperature heat pumps – turbo compressor elements



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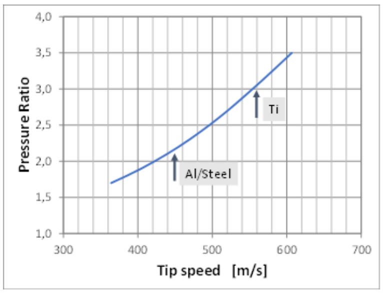
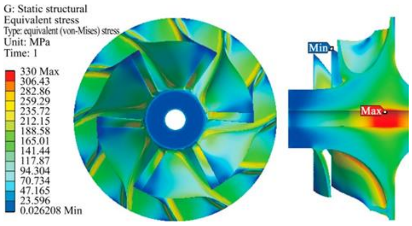
High temperature heat pumps – compressor tip speed





Tip speed limited by centrifugal forces and fatigue (peak stress level)

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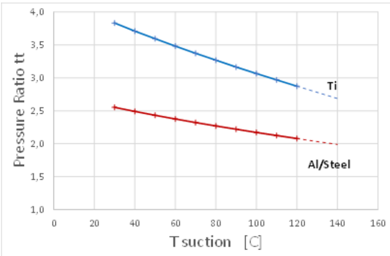
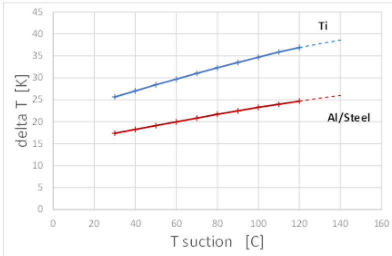
High temperature heat pumps – compressor Δp, ΔT





Max pressure ratio and corresponding temperature lift depends on inlet conditions

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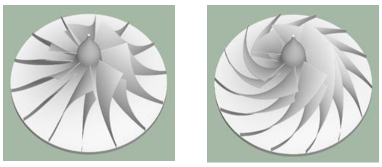
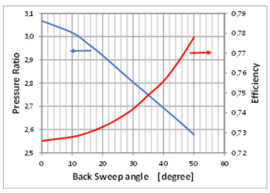
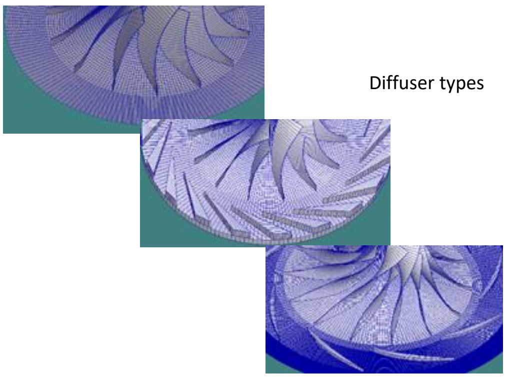
High temperature heat pumps – compressor design



Back sweep angle





Diffuser types

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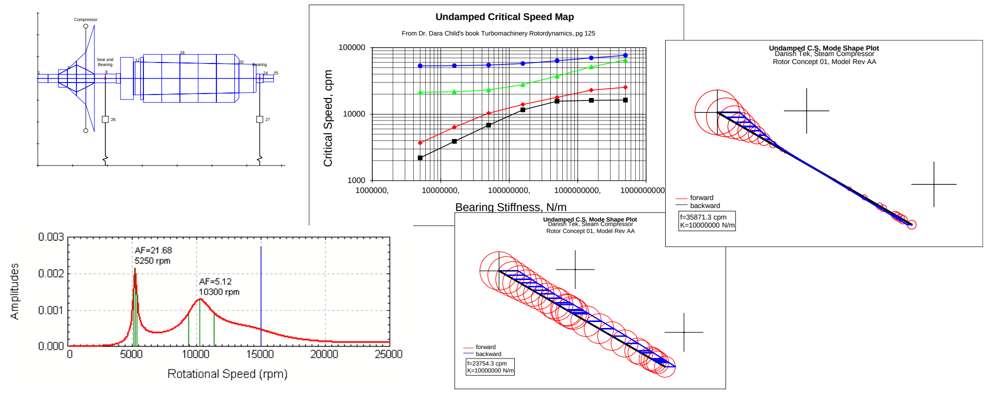
High temperature heat pumps – compressor rotordynamics



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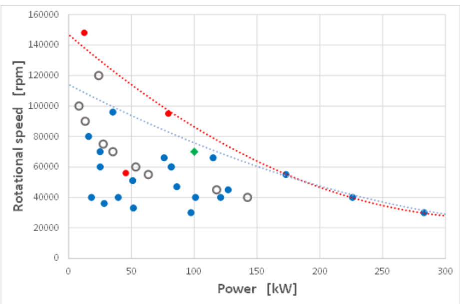
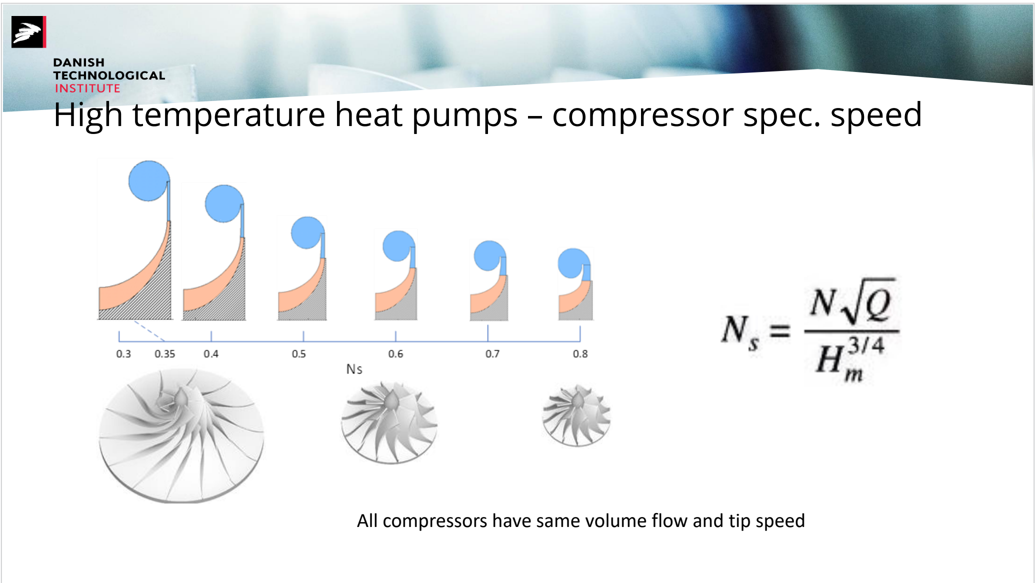
High temperature heat pumps – compressor drives

High speed motors,
induction and permanent magnet types



Selection of high-speed motors available for compressors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TECHNOLOGICAL
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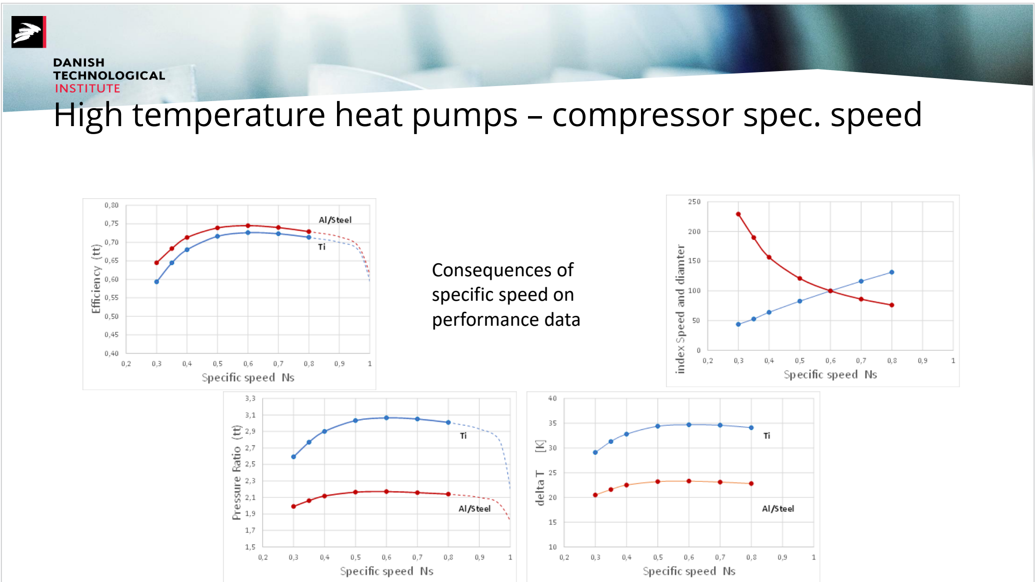
High temperature heat pumps – compressor spec. speed
0.3
0.35
0.4
0.5
0.6
0.7
0.8
Ns
$N_s = \frac{N\sqrt{Q}}{H_m^{3/4}}$
All compressors have same volume flow and tip speed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INSTITUTE
High temperature heat pumps – compressor spec. speed
Efficiency (tt)
Al/Steel
Ti
Specific speed Ns
Consequences of
specific speed on
performance data
index Speed and diamter
Specific speed Ns
Pressure Ratio (tt)
Ti
Al/Steel
Specific speed Ns
delta T [K]
Ti
Al/Steel
Specific speed Ns

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High temperature heat pumps – SuPrHeat considerations

Spindle compressor Hamburg vacuum	**Tunnel oven HTHP (ELFORSK)**	**SuPrHeat**
	150 kW 105/230C	500 kW 80/180C
Turbo compressor CSTechcom	**Innovative HTHP (Innobooster)**	SuPrHeat
	200 kW 80/110C	500 kW ??/??

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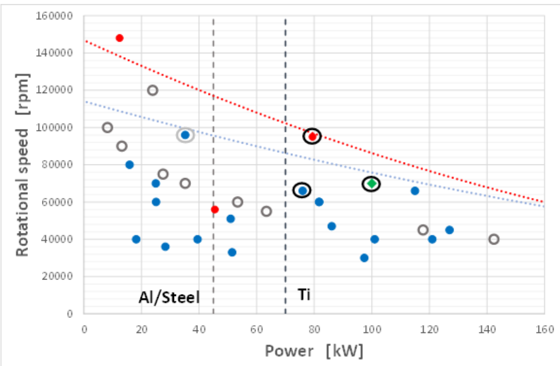
High temperature heat pumps – SuPrHeat considerations



Motor selection for 500 kW unit –
blue: existing motor,
red: concept motor,
green: Rotrex gear
dotted lines: new motor design

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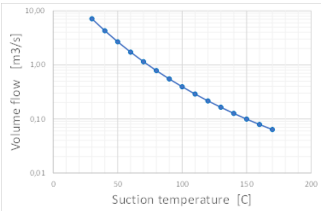
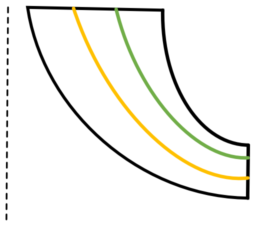
High temperature heat pumps – SuPrHeat considerations



Suction volume variation vs inlet pressure



Impeller inlet area have to be reduced with increasing inlet temperature for fixed tip speed –
black appr 80C inlet,
green appr 100C inlet
yellow appr 120C inlet

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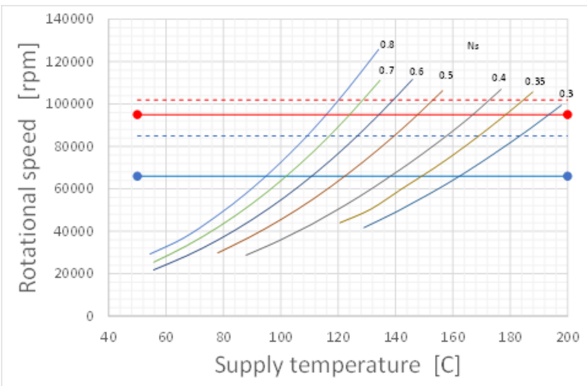
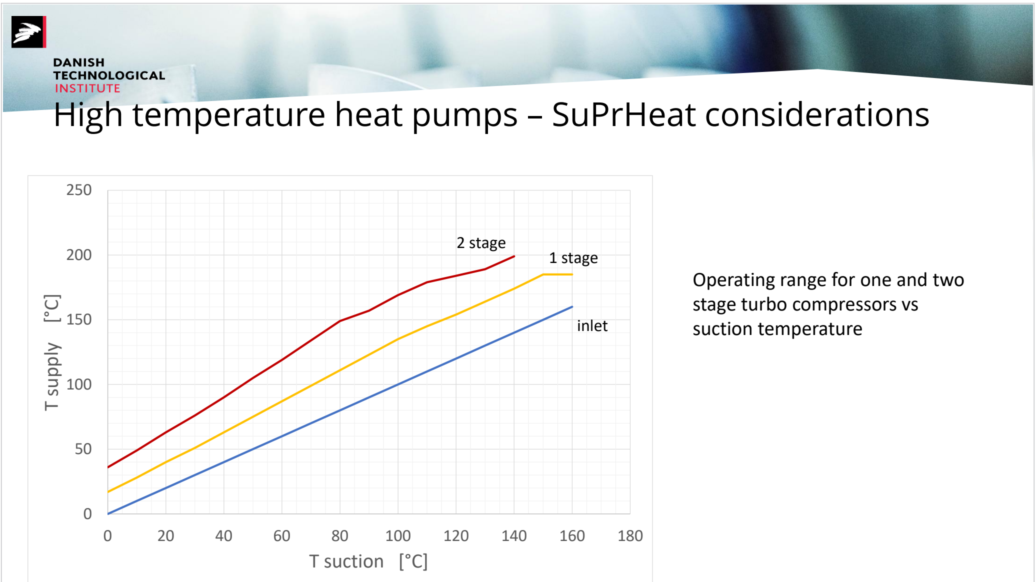
High temperature heat pumps – SuPrHeat considerations



Rotational speed vs supply temperature for the various specific speeds
The potential motor selections are indicated as the solid and dotted lines.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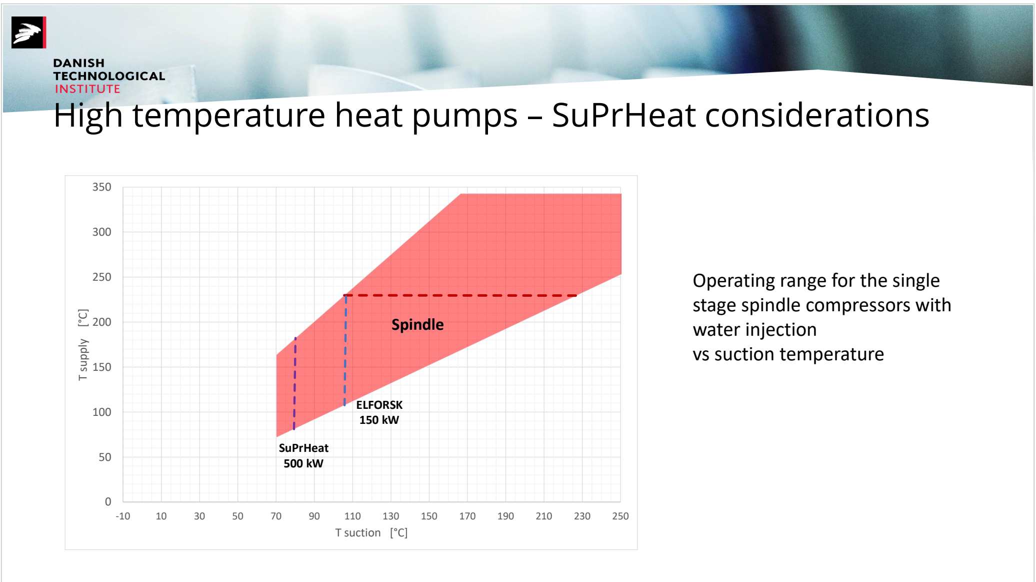
High temperature heat pumps – SuPrHeat considerations
T supply [°C]
T suction [°C]
2 stage
1 stage
inlet
Operating range for one and two stage turbo compressors vs suction temperature


DANISH TECHNOLOGICAL INSTITUTE
High temperature heat pumps – SuPrHeat considerations
T supply [°C]
T suction [°C]
Spindle
ELFORSK 150 kW
SuPrHeat 500 kW
Operating range for the single stage spindle compressors with water injection vs suction temperature

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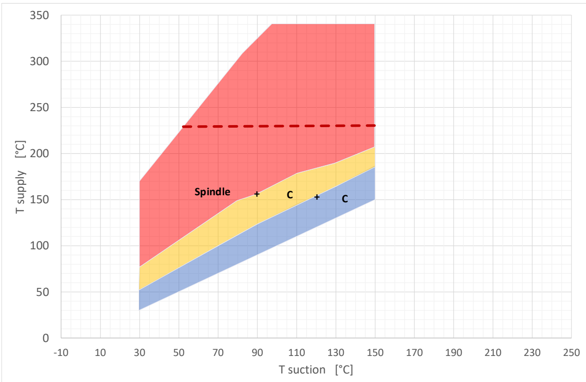
High temperature heat pumps – SuPrHeat considerations



Operating range for two-stage turbo compressor plus the single stage spindle compressors with water injection vs suction temperature

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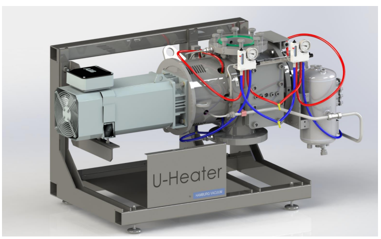
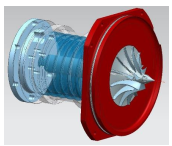
Thank you for your attention





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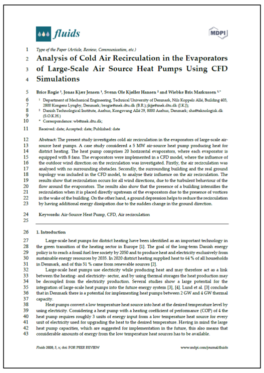
Brice Rogié

On the Influence of Air Recirculation in Large-Scale Air-Source Heat Pumps

13 September 2021 DTU Mechanical Engineering 2

Literature



This presentation is based on the paper titled "Analysis of Cold Air Recirculation in the Evaporators of Large-Scale Air Source Heat Pumps Using CFD Simulations" from the following authors:

Brice Rogie[1], Jonas Kjær Jensen[1], Svenn Ole Kjøller Hansen[2] and Wiebke Brix Markussen[1]

[1] DTU MEK, Lyngby

[2] Danish Technological Institute, Aarhus

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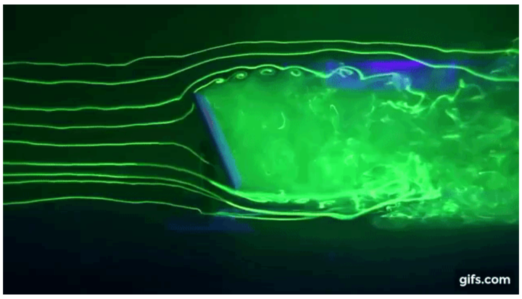
What is flow recirculation ?



Source: Google Sustainability "Vortex shedding is observed through flow visualization on a single heliostat in uniform (laminar) flow"

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Why should we bother ?

Condensers at DTU

- How does the flow look like ?
- Is the temperature at the inlet the ambient temperature ?
- What is the influence of wind, rain, snow, buildings, trees …

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The question we need to answer:

Is there recirculation for air-source heat pumps (spoiler: *yes there is*) and how does it affect the performances of the heat pump.

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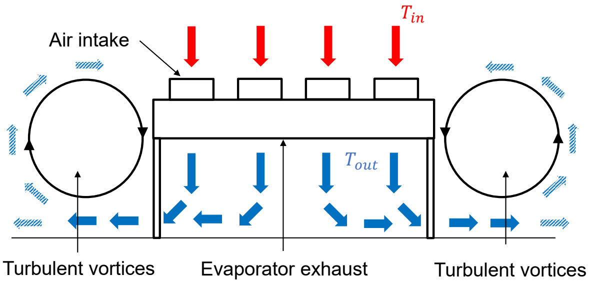
Flow recirculation in heat pumps

Example of an horizontal evaporator:



The inlet flow will be **mixed** with the colder outlet flow, decreasing the performances of the heat pump

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How to quantify recirculation ?

How much does T_{in} decrease ?

$$\varphi = 1 - \frac{T_{in} - T_{out}}{T_{\infty} - T_{out}}$$

T_{in} → Inlet Temperature
T_{out} → Outlet Temperature
T_{∞} → Ambient air Temperature

How to calculate φ ?

- On field experiments: very expensive, time consuming and sensitive to ambient condition,
- Scale model: expensive (wind tunnel), does the physics scale accurately?,
- Numerical study (CFD): inexpensive, fast, can reproduce any ambient conditions, **subject to numerical model errors/inaccuracies**.

13 September 2021 DTU Mechanical Engineering 8

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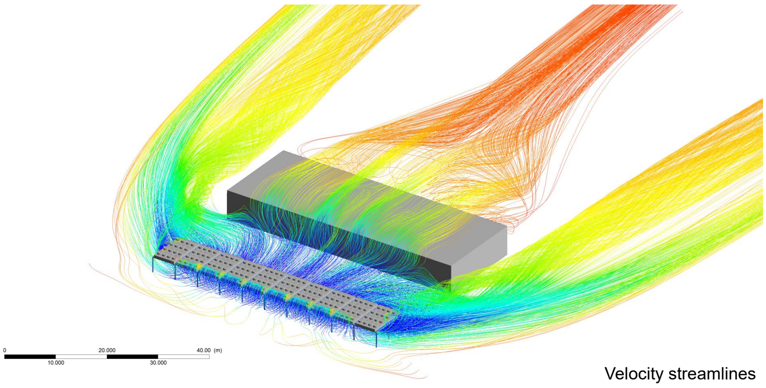
Computational Fluid Dynamics (CFD)

CFD is the partial-resolution of the Navier-Stokes (and Energy) equations using numerical schemes



Velocity streamlines

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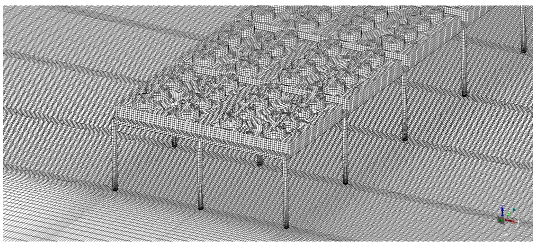
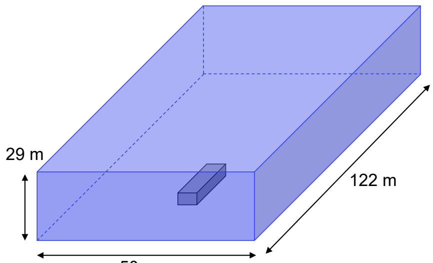
Computational Fluid Dynamics (CFD)

The CFD model requires a mesh where the equations are resolved for each mesh elements.



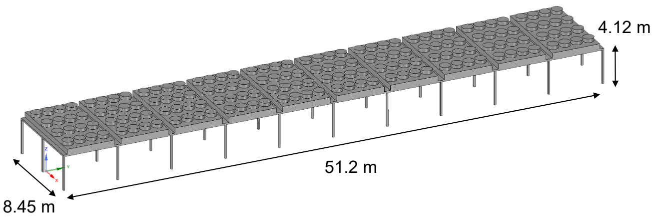


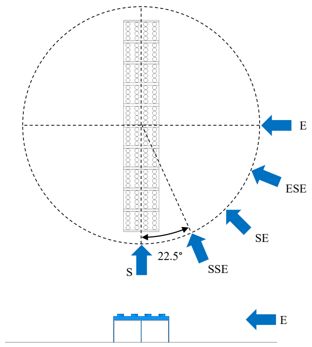
The surface is as big as a football field, with a mesh of 45 millions elements ! Therefore not everything can be modelled (heat exchangers, pipelines, …) and assumptions have to be made.

13 September 2021 DTU Mechanical Engineering 10

Test case n°1 – 5 MW heat pump at Brædstrup (DK), free flow (1)

20 Horizontal Evaporators (AlphaLaval Lu-Ve BD-1000)



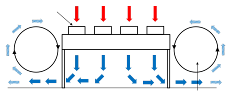


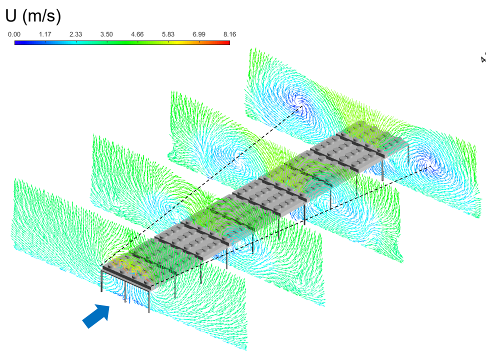
Boundary Conditions

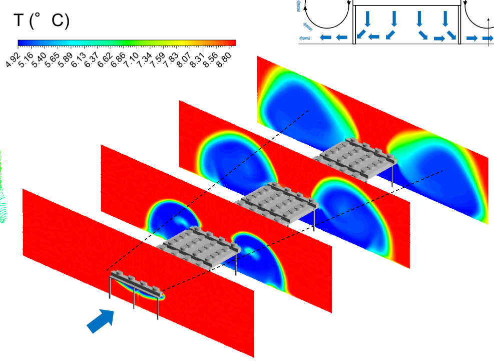
- Average wind speed of 3.7 m/s & Ambient temperature of 8.9°C (DMI),
- Evaporator inlet (8 intakes) mass flow rate of 640 kg/s,
- Air side temperature difference of 4 K.

Test case n°1 – 5 MW heat pump at Brædstrup (DK), free flow (2)

Velocity field (left) and temperature field (right) along the evaporators, for **South Wind**.

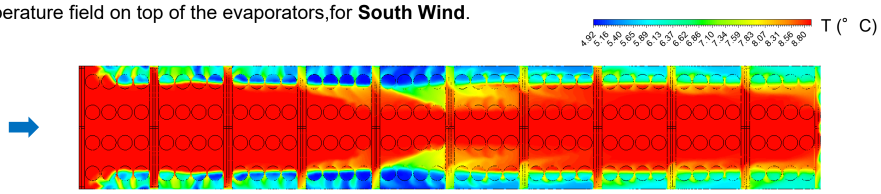


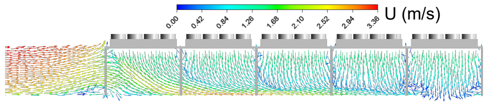




Test case n°1 – 5 MW heat pump at Brædstrup (DK), free flow (3)

Temperature field on top of the evaporators,for **South Wind**.



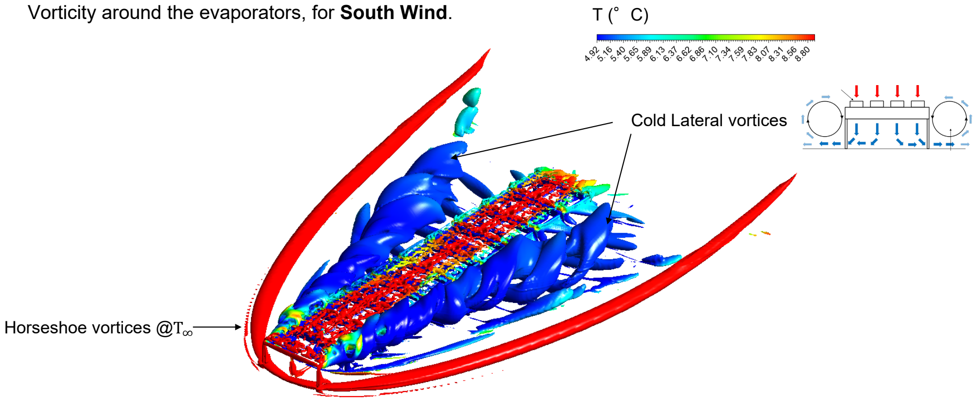


$$\varphi = 1 - \frac{T_{in} - T_{out}}{T_{\infty} - T_{out}} = 26.4\ \%$$

13 September 2021 DTU Mechanical Engineering 13

Test case n°1 – 5 MW heat pump at Brædstrup (DK), free flow (4)

Vorticity around the evaporators, for **South Wind**.



13 September 2021 DTU Mechanical Engineering 14

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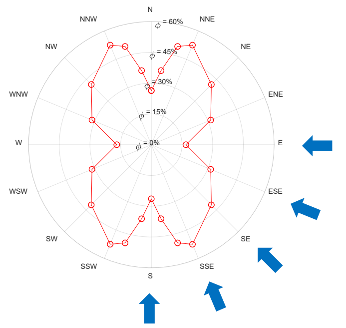
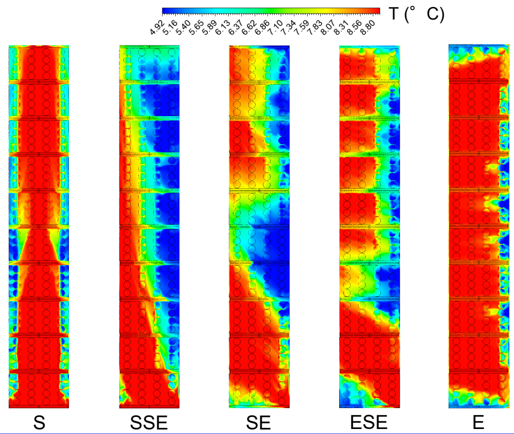
Test case n°1 – 5 MW heat pump at Brædstrup (DK), free flow (5)

Recirculation in function of wind direction



$\varphi_{min,\,E} = 16.9\ \%$

$\varphi_{max,\,SSE} = 52.5\ \%$



13 September 2021 DTU Mechanical Engineering 15

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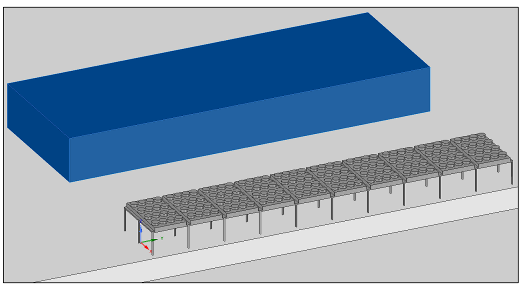
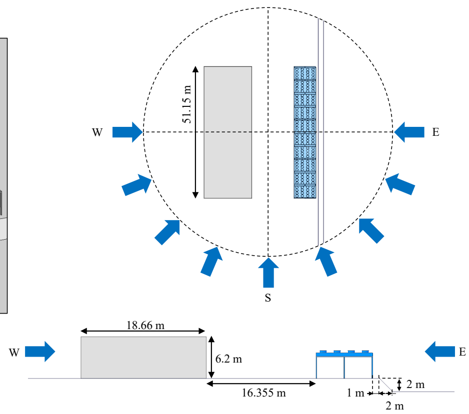
Test case n°2 – 5 MW heat pump at Brædstrup (DK), with obstacles (1)

20 Evaporators & 1 Building & Change in ground level

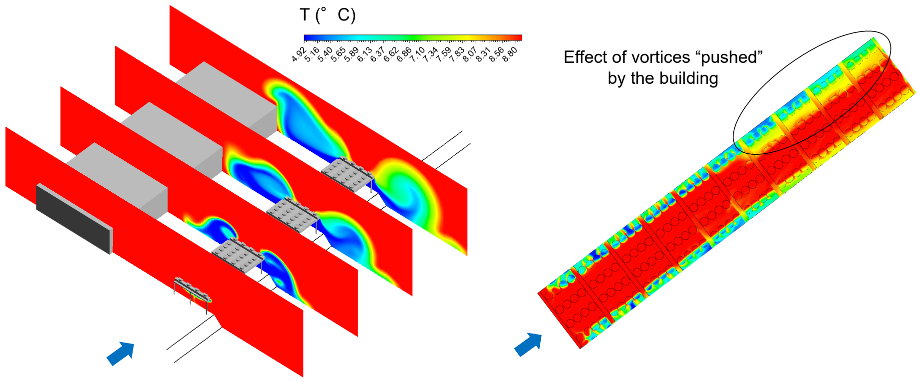




13 September 2021 DTU Mechanical Engineering 16

Test case n°2 – 5 MW heat pump at Brædstrup (DK), with obstacles (2)

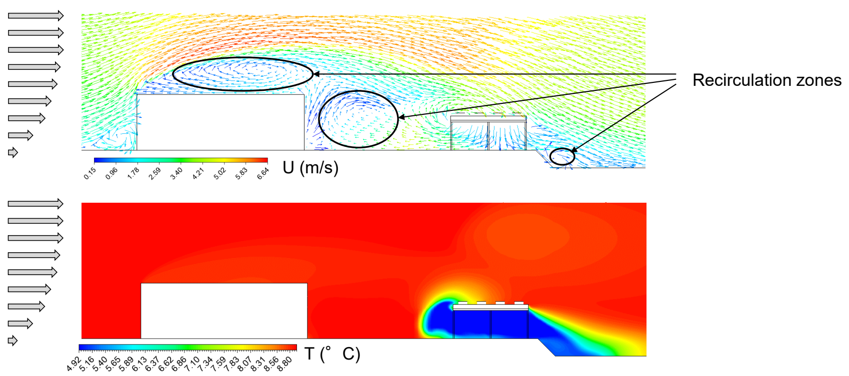
Temperature field (left) along the evaporators, for **South Wind**.



13 September 2021 DTU Mechanical Engineering 17

Test case n°2 – 5 MW heat pump at Brædstrup (DK), with obstacles (3)

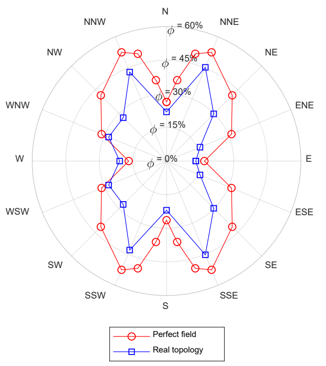
Velocity field (top) and temperature field (bot) along the building and evaporators, for **West Wind**.

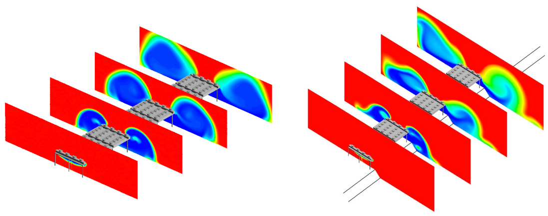


13 September 2021 DTU Mechanical Engineering 18

Test case n°2 – 5 MW heat pump at Brædstrup (DK), with obstacles (4)

Recirculation in function of wind direction





Overall recirculation reduction of 28%

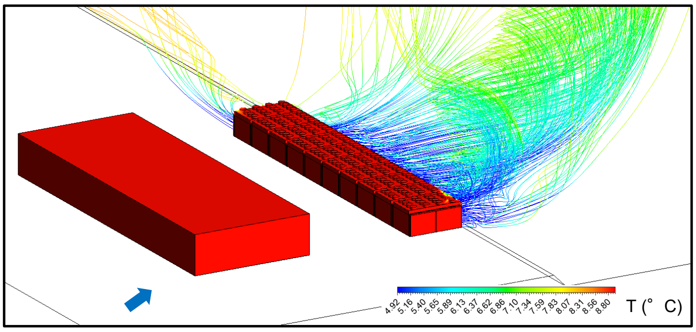
Conclusion

“Design” rules for air-recirculation

- Avoid longitudinal wind and associated turbulent vortices on the lateral sides,
- Avoid placing the evaporators in the wake of buildings (recirculation vortices),
- Decrease wind speed with “wind dissipative obstacles” (trees, bushes …),
- Example of good placement: Close to large trees, sheltered from wind ☺
- Example of bad placement: On top of windy hill ☹

Bonus: How to stop recirculation?

Add covers in function of the wind direction



$\varphi < 1\,\%$

13 September 2021 DTU Mechanical Engineering 21

MIREHP – Mixed Refrigerant Heat Pumps

A combined selection of working fluids and cycle layouts

Jonas Kjær Jensen
Senior Researcher, Ph.D
DTU Department of Mechanical Engineering

Introduction to the MIREHP project

Project funded by EUDP
(Danish Energy Agency)

Project consortium consisted of:

Introduction to the MIREHP project

- Main objective:

To investigate the efficiency gain due to the application zeotropic working fluids in heat pumps for industrial process heat supply.

Research tasks:

- Experimental investigation on a CO_2 – hydrocarbon mixture heat pump
- Numerical investigation on the identification of best performing mixtures and cycles

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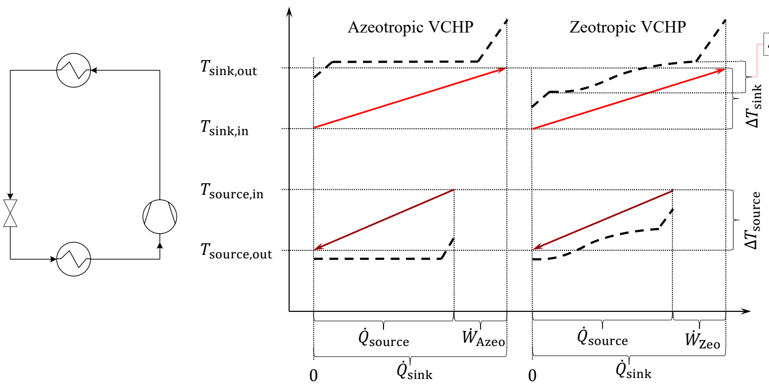
Zeotropic mixture heat pumps



$$\dot{\Gamma}_{s,gen} = \int_i^o \frac{1}{T_L(\dot{Q})} - \frac{1}{T_H(\dot{Q})} d\dot{Q}$$

$$\dot{\Gamma}_{s,gen,zeo} < \dot{\Gamma}_{s,gen,azeo}$$

$$\dot{W}_{zeo} < \dot{W}_{azeo}$$

04 October 2021 — 7th International Symposium on Advances in Refrigeration and Heat Pump Technology — 5

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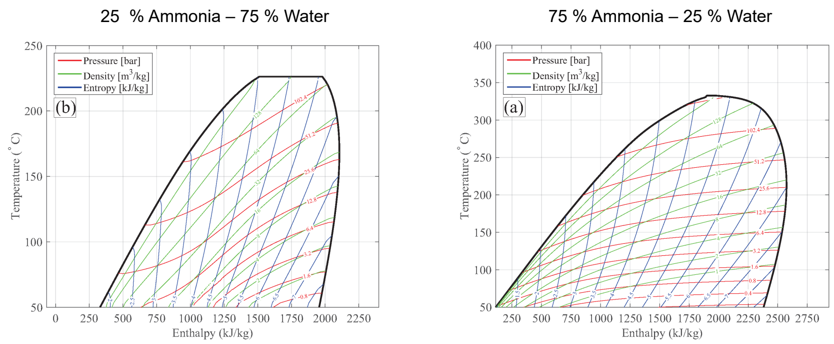
Advanced cycles layouts for zeotropic mixtures



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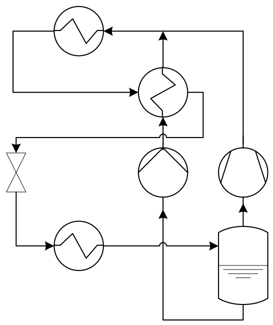
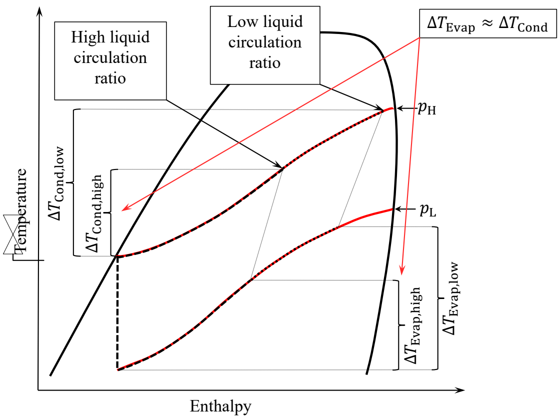
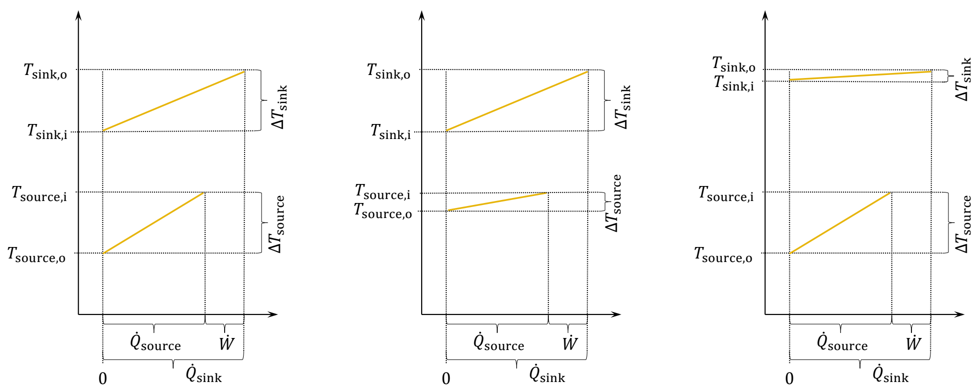
Advanced cycles layouts for zeotropic mixtures



(c) Standard HACHP i.e Osenbrück heat pump



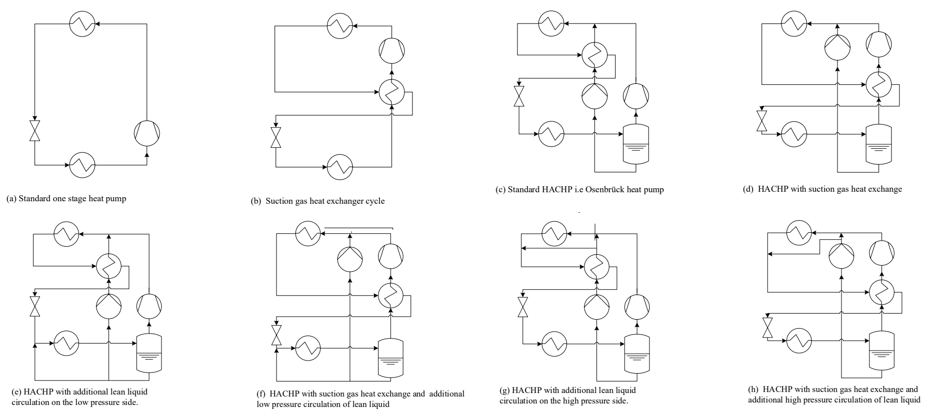
Advanced cycles layouts for zeotropic mixtures



Methodology

- Identified cycle configurations that allow greater control on working fluid temperature glides
- Developed models of identified cycle configurations
- Identified relevant pure fluids that could be used to form the needed mixtures
- Identified a representative set of operating conditions accounting for:
  - Heat supply temperature
  - Sink temperature glide
  - Source temperature glide
  - Temperature lift
- Performed simulations of all configurations, with all mixtures under all operating conditions
- For each simulation optimum mixture composition and recirculation ratios are found
- Analyzed the data to identify best mixtures and cycle configuration options

Methodology – Cycle configurations



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Methodology – Investigated fluids

No	Name of Fluid	Ref. No.:	Type	ODP -	GWP -	Normal Boiling Point °C	Crit. Temp. °C	Crit. Pres. bar	Safety Class
1	Methane	R50	HC	0	25	-161.5	-82.6	46.0	A3
2	Ethylene	R1250	HO	0	6.8	-103.8	9.2	50.4	A3
3	Ethane	R170	HC	0	2.9	-88.6	32.2	48.7	A3
4	CO_2	R744	Nat.	0	1.0	-	31.0	73.8	A1
5	Propylene	R1270	HO	0	3.1	-47.6	91.1	46.7	A3
6	Propane	R290	HC	0	3.0	-42.0	96.7	42.5	A3
7	Dimethylether (DME)	RE170	HC	0	1.0	-24.0	127.3	53.4	A3
8	Iso-Butane	R600a	HC	0	3.0	-11.7	134.7	36.3	A3
9	n-Butane	R600	HC	0	3.0	-0.5	152.0	38.0	A3
10	Iso-Pentane	R601a	HC	0	4.0	27.8	187.3	33.8	A3
11	Ethylether (DEE)	R610	HC	0	4.0	34.6	193.7	36.4	A3
12	Pentane	R601	HC	0	4.0	36.1	196.6	33.7	A3
13	n-Hexane		HC	-	-	68.7	234.5	30.3	-
14	Heptane		HC	-	-	98.4	267.0	27.4	-
15		R1234yf	HFO	0	4.0	243.6	367.8	33.8	A2L
16		R1234ze(E)	HFO	0	7.0	254.1	382.5	36.3	A2L
17		R1234ze(Z)	HFO	0	10	282.8	423.2	35.3	-
18		R1233zd(E)	HFO	0	4.5	291.4	439.6	36.2	A1
19		R134a	HFC	0	-	247.0	374.2	40.5	A1
20	Ammonia	R-717	Nat.	0	0.0	-33.3	132.4	112.8	B2
21	Water	R-718	Nat.	0	0.2	100.0	373.9	220.6	A1

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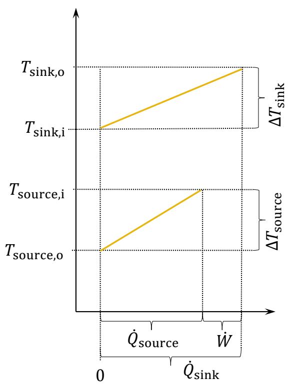
Methodology – Operating Conditions

Case Number	Heat Source $T_{source,in} \rightarrow T_{source,out}$	Heat Sink $T_{sink,in} \rightarrow T_{sink,out}$	ΔT_{source}	ΔT_{sink}	ΔT_{lift}
I	40 °C → 35 °C	45 °C → 50 °C	5 K	5 K	15 K
II	40 °C → 10 °C	45 °C → 50 °C	30 K	5 K	40 K
III	40 °C → 35 °C	45 °C → 75 °C	5 K	30 K	40 K
IV	40 °C → 10 °C	45 °C → 75 °C	30 K	30 K	65 K
V	40 °C → 35 °C	65 °C → 70 °C	5 K	5 K	35 K
VI	40 °C → 10 °C	65 °C → 70 °C	30 K	5 K	60 K
VII	40 °C → 35 °C	65 °C → 95 °C	5 K	30 K	60 K
VIII	40 °C → 10 °C	65 °C → 95 °C	30 K	30 K	85 K



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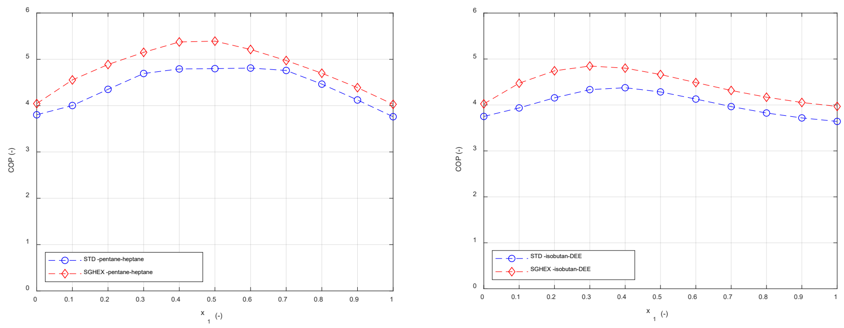
Results - STD and SGHEX



Comparison of the STD and SGHEX cycle for the mixtures pentane-heptane and isobutene-DEE. Both for operating condition case IV

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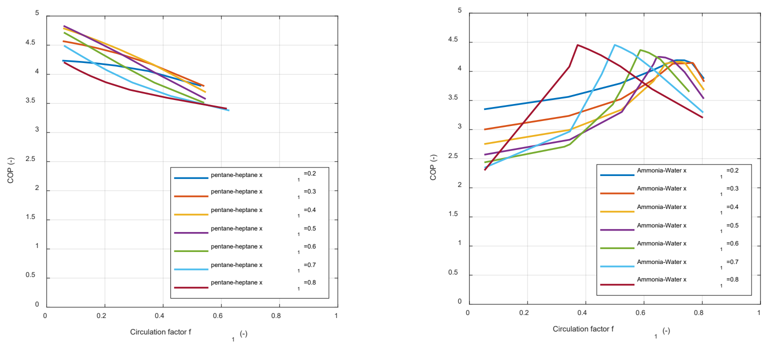
Results - HACHP



COP as a function of liquid circulation factor f_1 over a range of compositions for the mixtures pentane-heptane (left) and ammonia-water (right). Both are presented for Case IV

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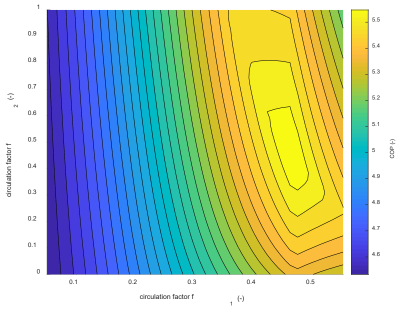
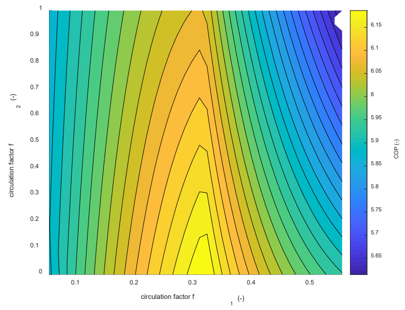
Results – HACHP with low pressure recirculation





COP as a function of circulation rate f_1 and f_3 for two different mixtures: 70 % DEE-Heptane (left) and 60 % Hexane-Heptane (right). Both for case V

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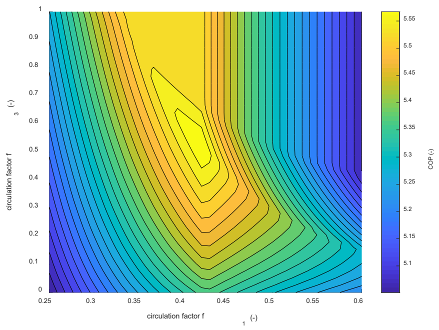
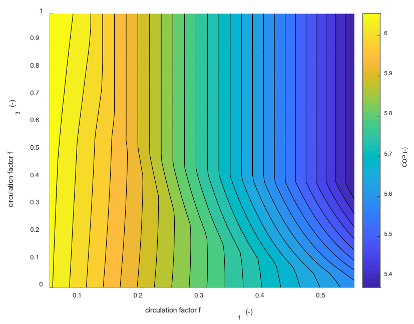
Results – HACHP with high pressure recirculation





COP as a function of circulation rate f_1 and f_2 for two different mixtures: 70 % pentane-heptane for case V (left) and 80 % DEE-Heptane for case III (right).

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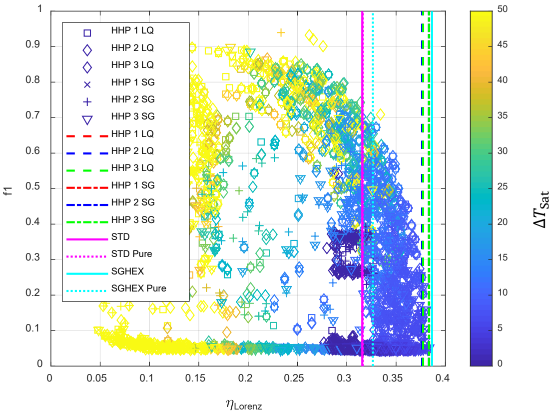
Results



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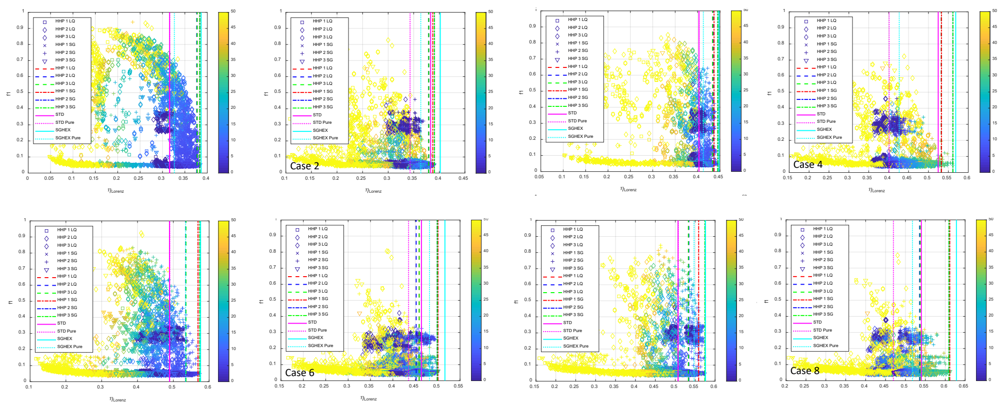
Results – Final results of simualtions



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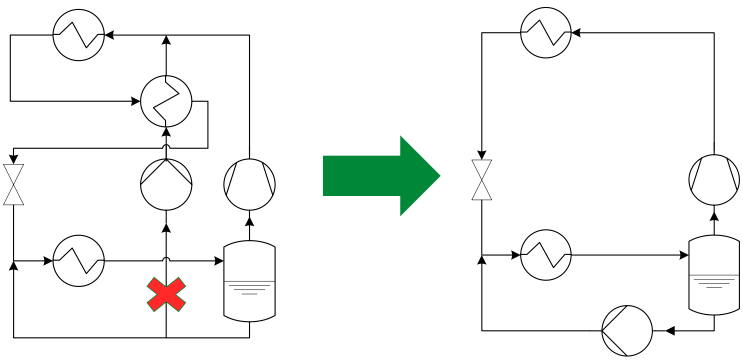
Results - ELCHP



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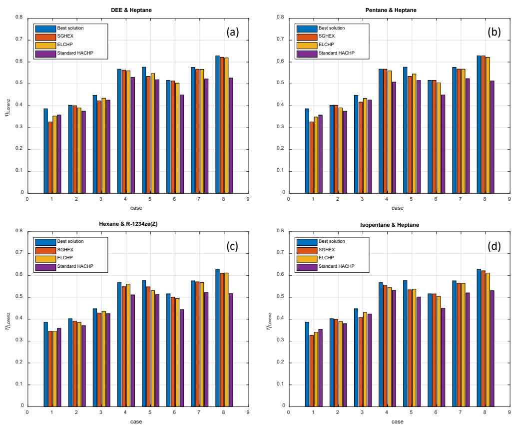
Results – Approaching best performance with selected mixtures



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Conclusion and recommendations

- For a given cycle performance can be improved by choosing an appropriate mixture
- For a given mixture performance can be improved by choosing an appropriate cycle
- If one can freely chose mixture and composition: SGHEX always attain the best results
- If the choice of mixture is constraint or limited advanced cycles may be needed ensure the best possible performance under all operating conditions

FARS – Future Ammonia Refrigeration Systems

Niels Vestergaard – Danfoss Industrial Rerfrigeration

2021-10-04

Køle-og Varmepumpeforum 2021

7th International Symposium on Advances in Refrigeration and Heat Pump Technology

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Outline

Introduction

- Scope of this presentation
- Drivers for low charge ammonia
- Refrigerant charge in various systems
  - Pumped systems
  - Direct expansion systems
- Two-phase measuring methods tested
- How to ensure reliable two-phase measurements
- Conclusions

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Project content

FARS – Future Ammonia Refrigeration Systems

- Reduce charge in liquid overfeed systems without compromising cooling capacity
- Reduce charge in DX systems without compromising cooling capacity
- Develop and test finned and tube & Microchannel evaporators

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Refrigerants: Ammonia

Ammonia
Facts

- Natural refrigerant
- GWP=0
- ODP=0
- Environmentally friendly
- High efficiency
- Low Cost
- Widely available
- Self-alarming – by odour
- Ammonia is the dominant refrigerant in industrial systems.
- Specific design requirements needed, do to ammonia's classification as ***toxic and mild flammable fluid.***

Ammonia is the natural choice

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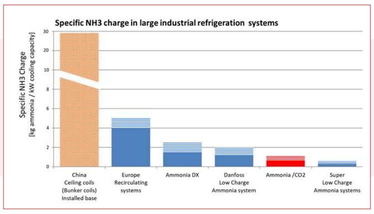
Ammonia in Industrial Refrigeration systems



Status

- Ammonia is a very effective and natural refrigerant

Challenge

- Increased focus on large ammonia charges in populated areas.
- Increased safety requirements for systems with large ammonia charges.
- Recent accidents in APAC increase the negative focus on ammonia systems.

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Offsite risk mitigation by charge reduction / segmentation

4 MW ammonia system
Charge: 5 kg / kW
20.000 kg

A – Increase general safety level of system.
- Documented risk assessment.
- Offsite risk assessment.
- Safety quick closing section valves.
- Safety gas detection.
- Etc.

R717-charge
1 x 20.000 kg
(5 kg / kW)

B – Sub-segments
- Design system with a number of sub-segments, which can be separated from each other in the event of leakage.

R717-charge e.g.
4 x 5.000 kg
(5 kg / kW)

C – Ammonia-DX system
- Ammonia DX-system reduce the required liquid charge

R717-charge e.g.
2 x 5.000 kg
(2,5 kg / kW)

D – Ammonia-CO2
- Ammonia-CO2 cascade system or Ammonia-CO2 brine system

R717-charge
~2.000 kg
(0,5 kg / kW)

E – Low-charge Ammonia units
- Install a number of rooftop mounted self-contained ammonia units

R717-charge e.g.
8 x 200 kg
(0,4 kg / kW)

Charge reduction is an attractive mitigation solution.

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Reduced charge => Reduced Risk

Example: Cold Store 2300 kW - (Built in China 2014)

Ammonia Ceiling Coil system		Ammonia DX system with Aluminum Air Coolers	
Type of evaporators	**Ammonia charge (kg)**	**Ammonia charge (kg /kW)**	**Charge reduction (%)**
U bend ceiling coil (OD,38mm; ID, 32mm)	59869	26	**94%**
Aluminum DX Air coolers	3680	1.6	

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Low Charge Ammonia units for cold storage

Mitigating risks

New innovative and compact ammonia system design opens the door for new applications

- *No need for an engine room*
- *Roof-top based design*
- *"VLC" very low NH3 charge*
- ***Claimed to have up to 98% less ammonia than regular systems*** *(lowest charge < 100 g / kW)*
- *Fully automated, self-contained NH3 system*
- *Very fast installation*

1 DX-system

2 LPR-system

3 Pump-system

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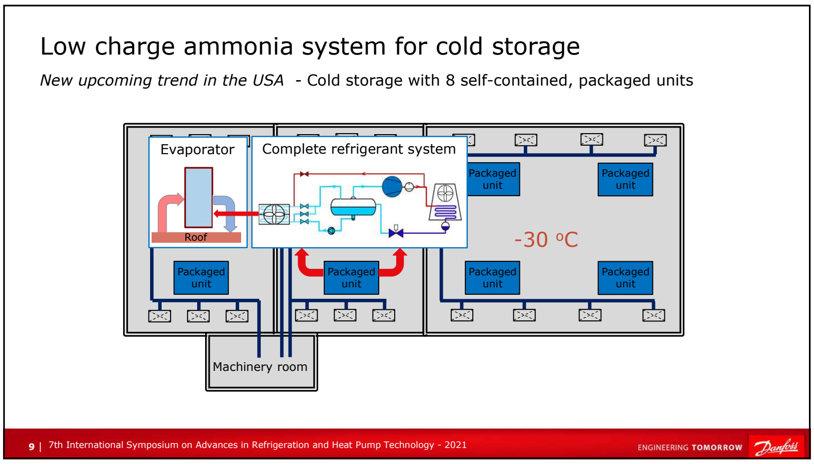

Low charge ammonia system for cold storage
New upcoming trend in the USA - Cold storage with 8 self-contained, packaged units
Evaporator
Complete refrigerant system
Roof
Packaged unit
-30 °C
Machinery room
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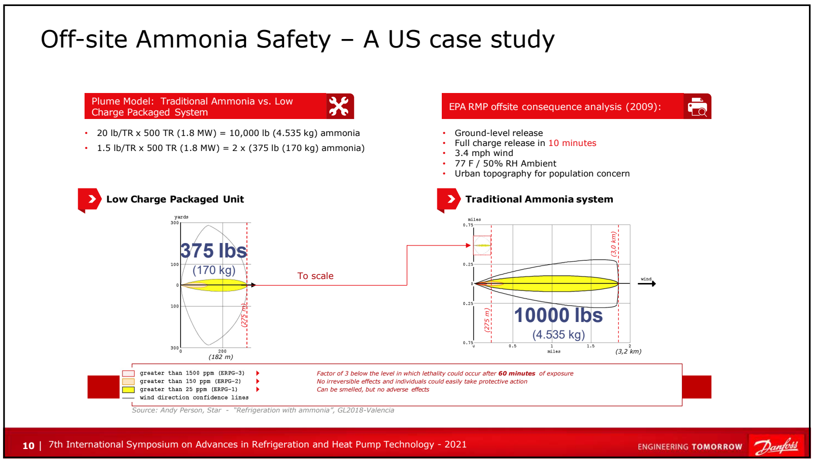

Off-site Ammonia Safety – A US case study
Plume Model: Traditional Ammonia vs. Low Charge Packaged System
20 lb/TR x 500 TR (1.8 MW) = 10,000 lb (4.535 kg) ammonia
1.5 lb/TR x 500 TR (1.8 MW) = 2 x (375 lb (170 kg) ammonia)
EPA RMP offsite consequence analysis (2009):
Ground-level release
Full charge release in 10 minutes
3.4 mph wind
77 F / 50% RH Ambient
Urban topography for population concern
Low Charge Packaged Unit
Traditional Ammonia system
375 lbs
(170 kg)
To scale
10000 lbs
(4.535 kg)
(182 m)
(275 m)
(3,0 km)
(3,2 km)
greater than 1500 ppm (ERPG-3)
greater than 150 ppm (ERPG-2)
greater than 25 ppm (ERPG-1)
wind direction confidence lines
Factor of 3 below the level in which lethality could occur after 60 minutes of exposure
No irreversible effects and individuals could easily take protective action
Can be smelled, but no adverse effects
Source: Andy Person, Star - "Refrigeration with ammonia", GL2018-Valencia
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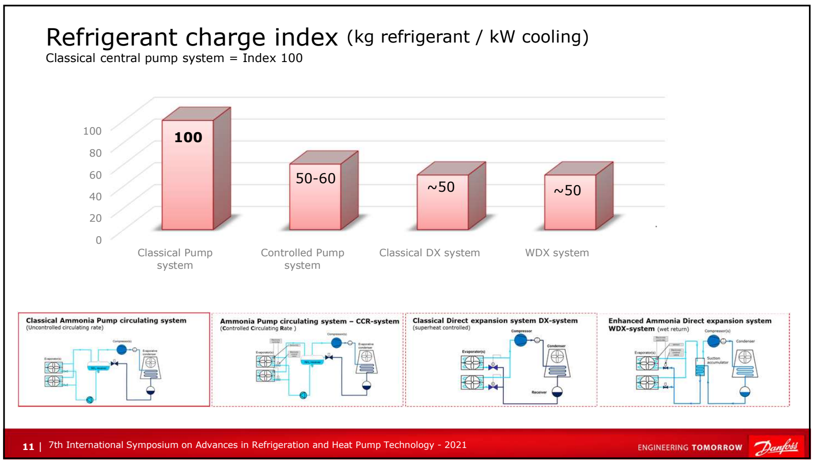
Refrigerant charge index (kg refrigerant / kW cooling)
Classical central pump system = Index 100
100
80
60
40
20
0
100
50-60
~50
~50
Classical Pump system
Controlled Pump system
Classical DX system
WDX system
Classical Ammonia Pump circulating system
Ammonia Pump circulating system – CCR-system
Classical Direct expansion system DX-system
Enhanced Ammonia Direct expansion system WDX-system
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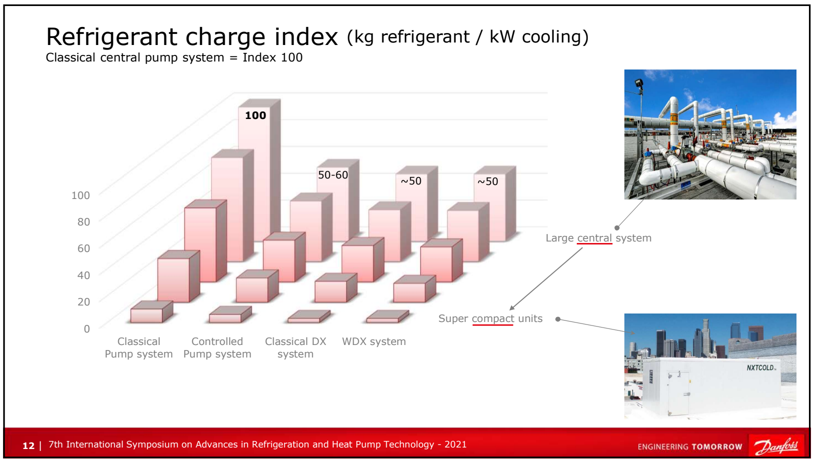
Refrigerant charge index (kg refrigerant / kW cooling)
Classical central pump system = Index 100
100
80
60
40
20
0
100
50-60
~50
~50
Large central system
Super compact units
Classical Pump system
Controlled Pump system
Classical DX system
WDX system
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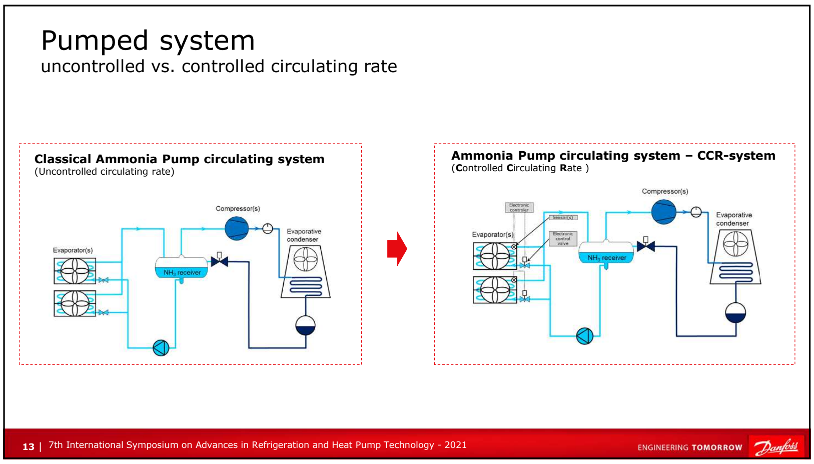
Pumped system
uncontrolled vs. controlled circulating rate
Classical Ammonia Pump circulating system
(Uncontrolled circulating rate)
Compressor(s)
Evaporative condenser
Evaporator(s)
Ammonia Pump circulating system – CCR-system
(Controlled Circulating Rate)
Compressor(s)
Evaporative condenser
Evaporator(s)
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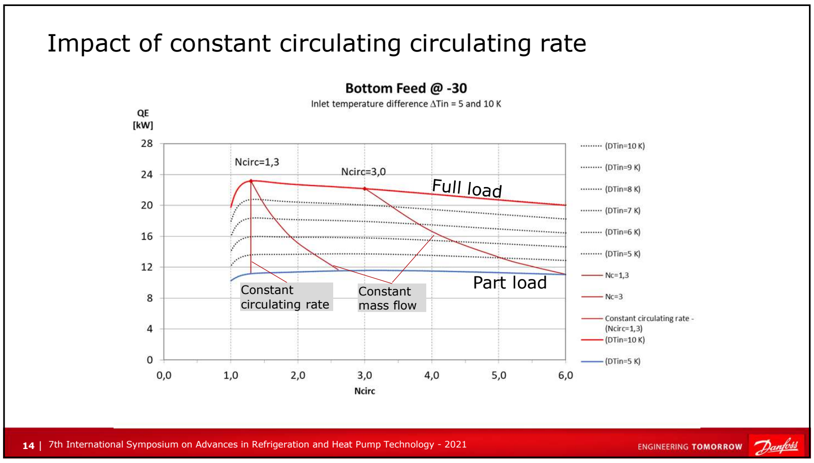
Impact of constant circulating circulating rate
Bottom Feed @ -30
Inlet temperature difference ΔTin = 5 and 10 K
QE [kW]
Ncirc=1,3
Ncirc=3,0
Full load
Part load
Constant circulating rate
Constant mass flow
Ncirc
(DTin=10 K)
(DTin=9 K)
(DTin=8 K)
(DTin=7 K)
(DTin=6 K)
(DTin=5 K)
Nc=1,3
Nc=3
Constant circulating rate - (Ncirc=1,3)
(DTin=10 K)
(DTin=5 K)
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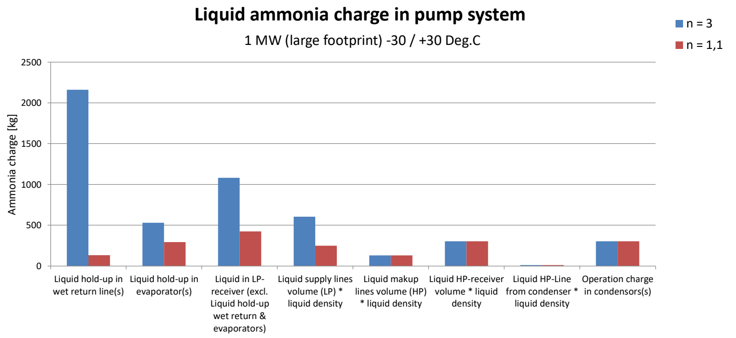
Analysis of liquid ammonia charge in pump system



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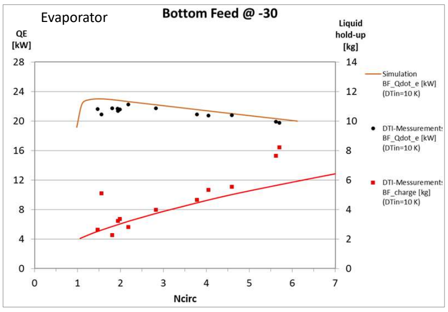
Pumped system

Liquid hold-up in evaporator vs. circulating rate



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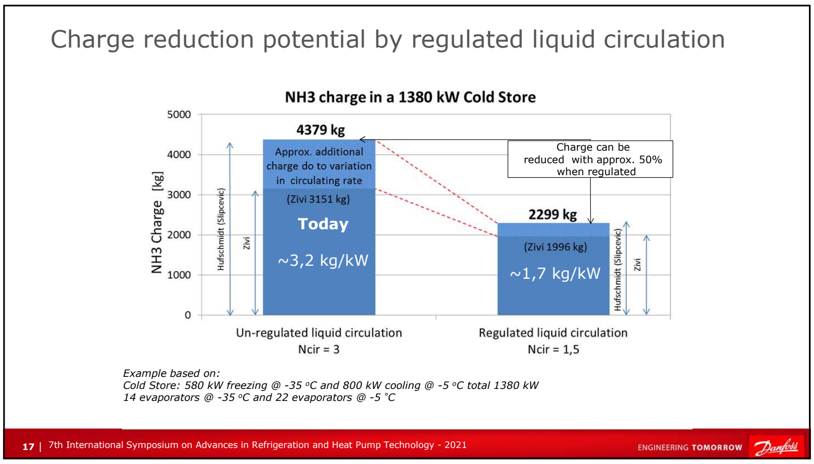
Charge reduction potential by regulated liquid circulation
NH3 charge in a 1380 kW Cold Store
4379 kg
Approx. additional charge do to variation in circulating rate
(Zivi 3151 kg)
Today
~3,2 kg/kW
2299 kg
(Zivi 1996 kg)
~1,7 kg/kW
Charge can be reduced with approx. 50% when regulated
NH3 Charge [kg]
Hufschmidt (Slipcevic)
Zivi
Un-regulated liquid circulation
Ncir = 3
Regulated liquid circulation
Ncir = 1,5
Example based on:
Cold Store: 580 kW freezing @ -35 °C and 800 kW cooling @ -5 °C total 1380 kW
14 evaporators @ -35 °C and 22 evaporators @ -5 °C
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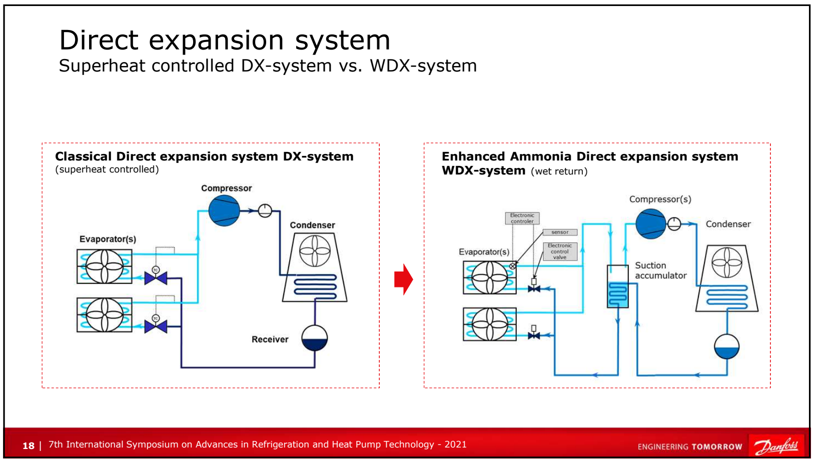
Direct expansion system
Superheat controlled DX-system vs. WDX-system
Classical Direct expansion system DX-system
(superheat controlled)
Compressor
Condenser
Evaporator(s)
Receiver
Enhanced Ammonia Direct expansion system
WDX-system (wet return)
Compressor(s)
Condenser
Evaporator(s)
Suction accumulator
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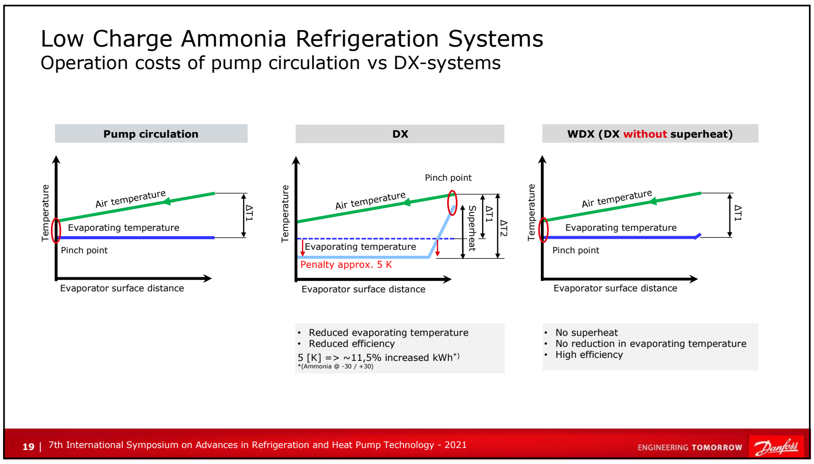

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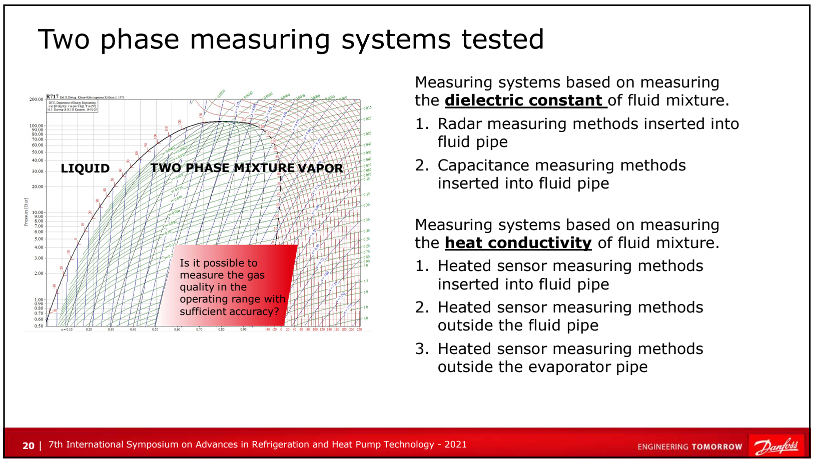

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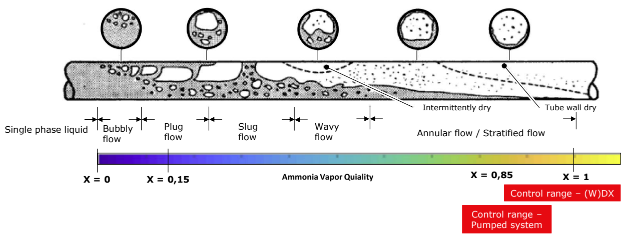
10

Flow pattern vs. gas quality



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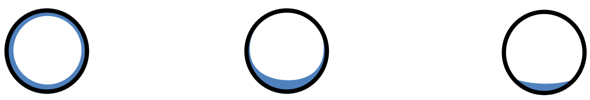
Flow pattern vs. gas velocity



- **Fully annular flow** (uniformed liquid film thickness)
- Evaporator with **very high superficial gas velocity (Ugas > 15 m/s)**

- **Partly annular flow** (uneven liquid film thickness)
- Evaporator with **high superficial gas velocity (Ugas ~ 10-15 m/s)**

- **Stratified flow** ("separated" gas and liquid flow.
- Very **low superficial gas velocity (Ugas 5-10 m/s)**

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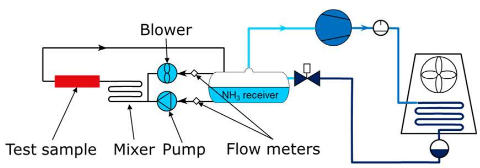
Test of two-phase sensors

Test of 2-phase measuring system with variation of following parameters:

- X-value, gas velocity, pipe size, temperature, flow direction and measuring principle



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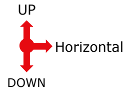
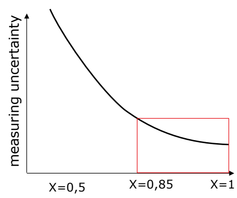
23

Flow regime – important parameters

1. Different flow directions create different flow regimes
2. Velocity (superficial gas velocity) has significant impact on flow regime.
3. Pipe dimension: The flow regime in a large pipe vs. small pipe, at same velocity, are not identical
4. Liquid accumulation: Flow in pipes with uneven diameters may accumulate liquids and interfere the measurements
5. Large liquid content (low x-value) increase the measuring uncertainty





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24

12

How to ensure reliable two-phase measurements with heated sensors

1. Limit the flow directions to horizontal flow
2. Measure and document the two-phase flow measurements within a defined velocity range
3. Measure and document the two-phase flow measurements within a defined diameter range (evaporator pipes from 10 to 20 mm)
4. Liquid accumulation affecting the measuring result must be avoided
5. Limit the measuring range to X-values > 0,85

With the above application range and tests, it is possible to predict the actual flow regime and conduct reliable two-phase measurements

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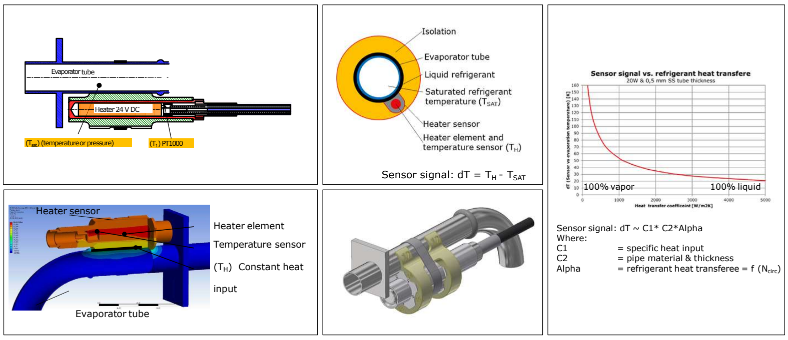
25

Heated sensor - outside the fluid pipe



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13

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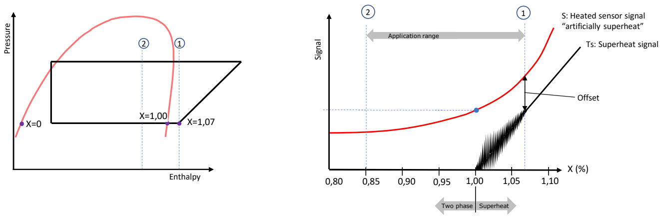
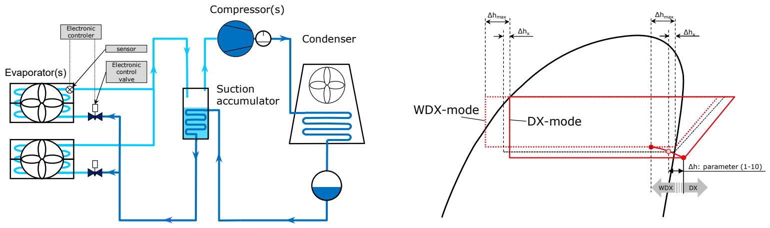
Superheat vs heated sensor signal



27

Ammonia DX vs. WDX

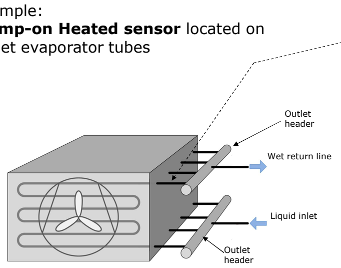
(Dry vs. Wet Direct Expansion)

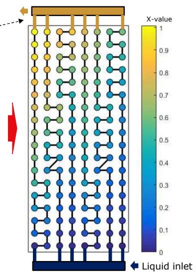


28

Pumped system with heated sensor

Example:
Clamp-on Heated sensor located on outlet evaporator tubes





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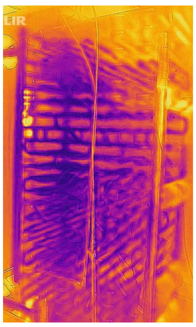
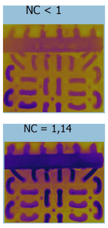
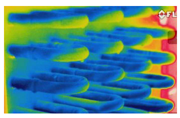
29

Various evaporator tests





Un-even distribution



Stratified flow

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30

Conclusions

Questions

1. Is it possible to measure the gas quality in the two-phase operating range with sufficient accuracy?

   <u>**YES**</u>, it is possible to measure the gas quality within a defined operating range, but it requires that the <u>actual flow regime can be predicted</u>

2. Is it possible to control a low charge ammonia system so the system reach a COP-value similar to a well-designed pump system or higher?

   <u>**YES**</u>, The test in the FARS-project shows that it is possible to obtain similar or higher COP-values

1. Is it possible to reduce the total charge of an ammonia system as predicted?
   <u>**YES**</u>, The test in the FARS-project shows that it is possible to reduce the charge as predicted on <u>component level</u>, but it has not yet been shown on system level. On system level factors like pipe sizing, calculator sizing and defrost method can affect the reduction on system level

31

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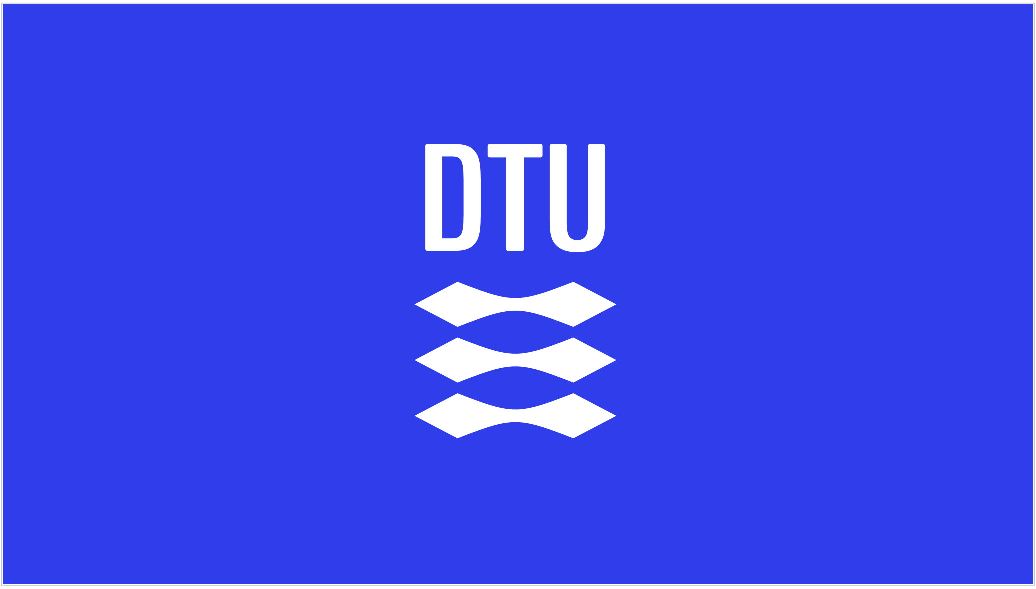
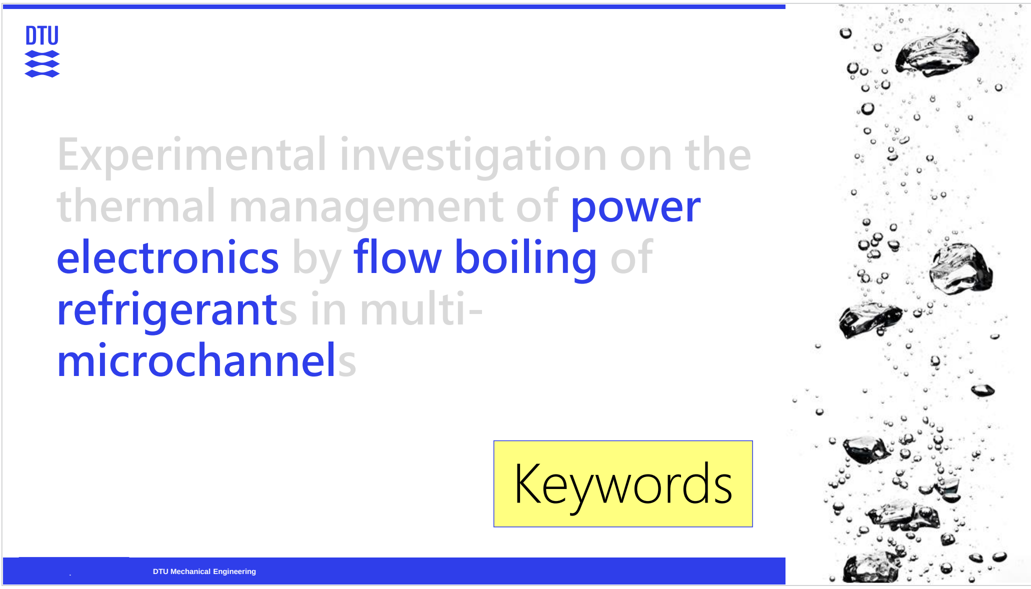
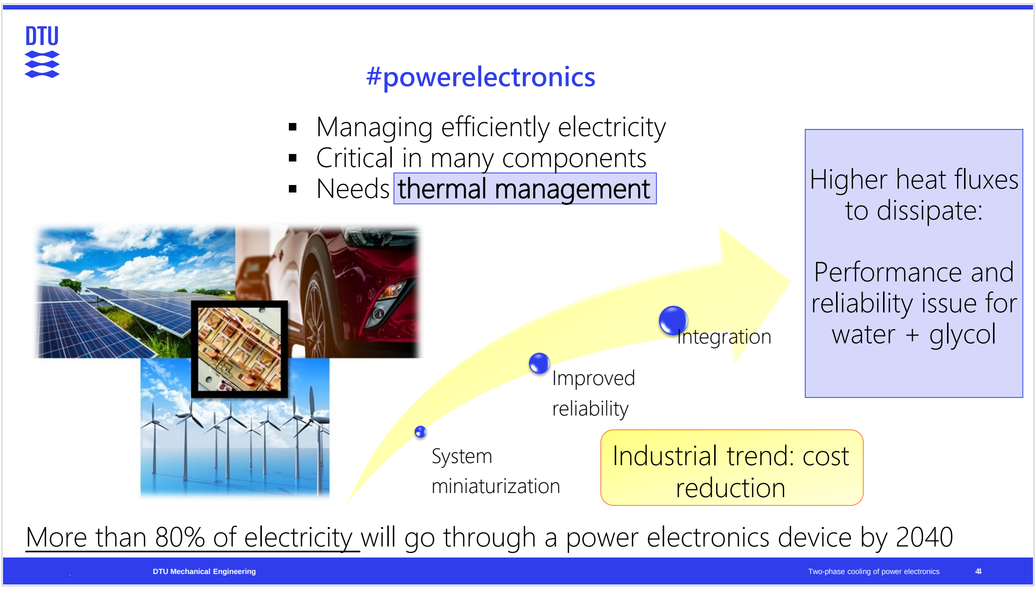
32


DTU


DTU
Experimental investigation on the thermal management of power electronics by flow boiling of refrigerants in multi-microchannels
Gennaro Criscuolo
7th International Symposium in Refrigeration and Heat Pump Technology
4th October 2021
DTU Mechanical Engineering


DTU
Experimental investigation on the thermal management of power electronics by flow boiling of refrigerants in multi-microchannels
Keywords
DTU Mechanical Engineering


DTU
#powerelectronics
▪ Managing efficiently electricity
▪ Critical in many components
▪ Needs thermal management
Higher heat fluxes to dissipate:
Performance and reliability issue for water + glycol
Integration
Improved reliability
System miniaturization
Industrial trend: cost reduction
More than 80% of electricity will go through a power electronics device by 2040
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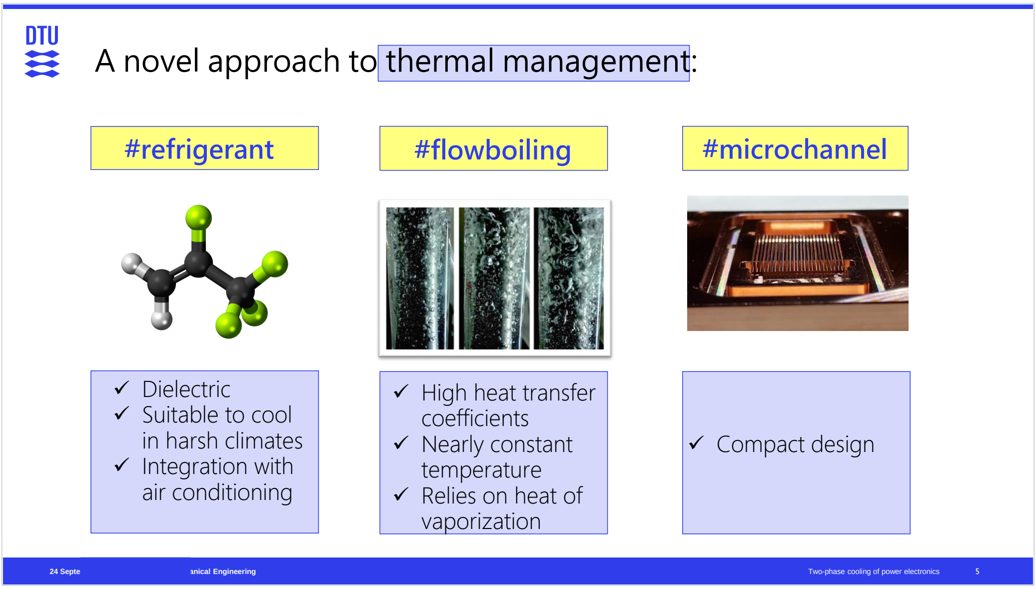
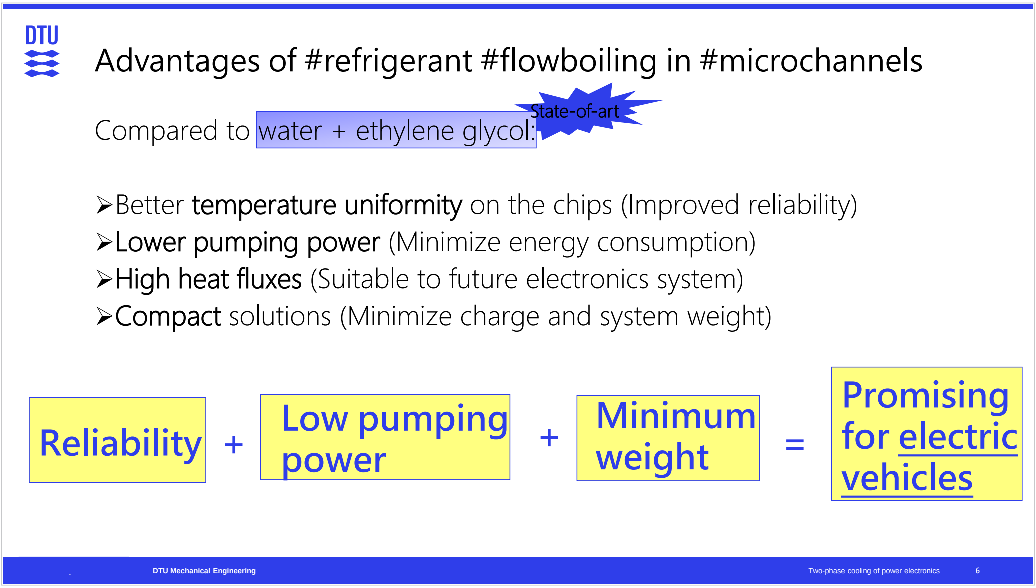
Two-phase cooling of power electronics
4


A novel approach to thermal management:
#refrigerant
#flowboiling
#microchannel
✓ Dielectric
✓ Suitable to cool in harsh climates
✓ Integration with air conditioning
✓ High heat transfer coefficients
✓ Nearly constant temperature
✓ Relies on heat of vaporization
✓ Compact design
Two-phase cooling of power electronics
5


Advantages of #refrigerant #flowboiling in #microchannels
Compared to water + ethylene glycol:
State-of-art
➢Better temperature uniformity on the chips (Improved reliability)
➢Lower pumping power (Minimize energy consumption)
➢High heat fluxes (Suitable to future electronics system)
➢Compact solutions (Minimize charge and system weight)
Reliability + Low pumping power + Minimum weight = Promising for electric vehicles
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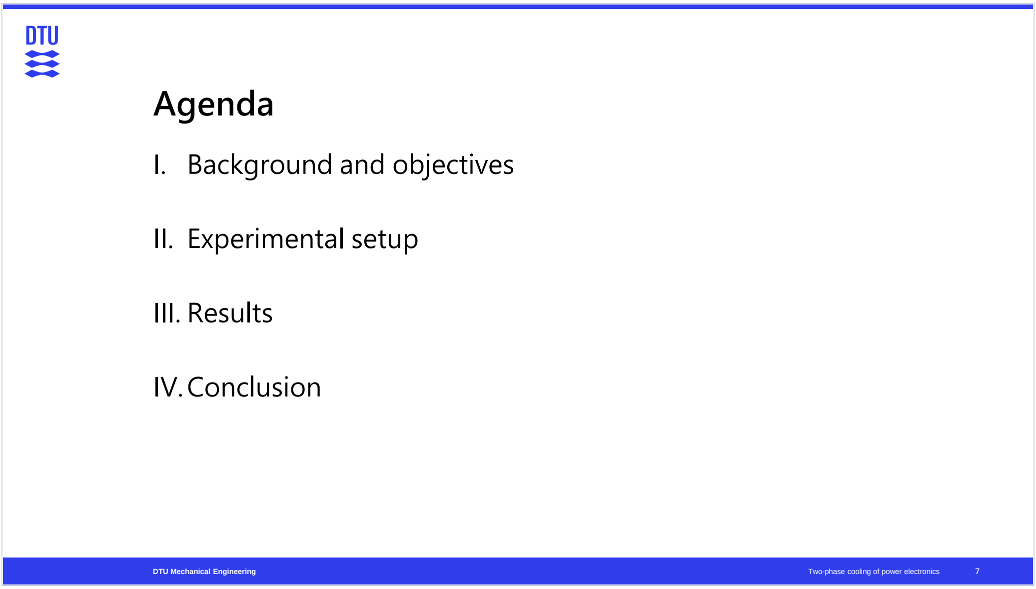
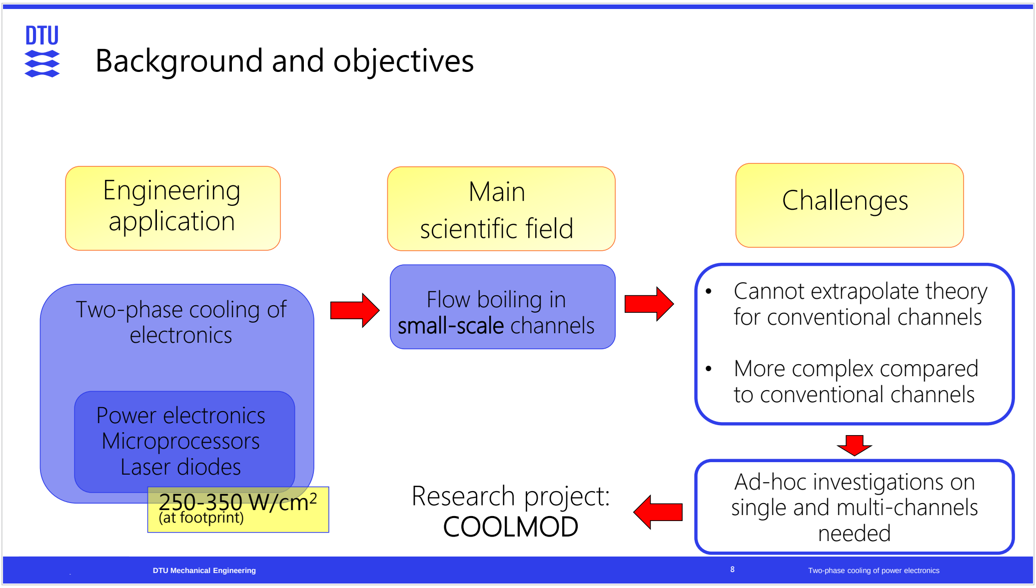
Two-phase cooling of power electronics
6


DTU
Agenda
I. Background and objectives
II. Experimental setup
III. Results
IV. Conclusion
DTU Mechanical Engineering
Two-phase cooling of power electronics
7


DTU
Background and objectives
Engineering application
Main scientific field
Challenges
Two-phase cooling of electronics
Power electronics
Microprocessors
Laser diodes
250-350 W/cm²
(at footprint)
Flow boiling in small-scale channels
Cannot extrapolate theory for conventional channels
More complex compared to conventional channels
Ad-hoc investigations on single and multi-channels needed
Research project: COOLMOD
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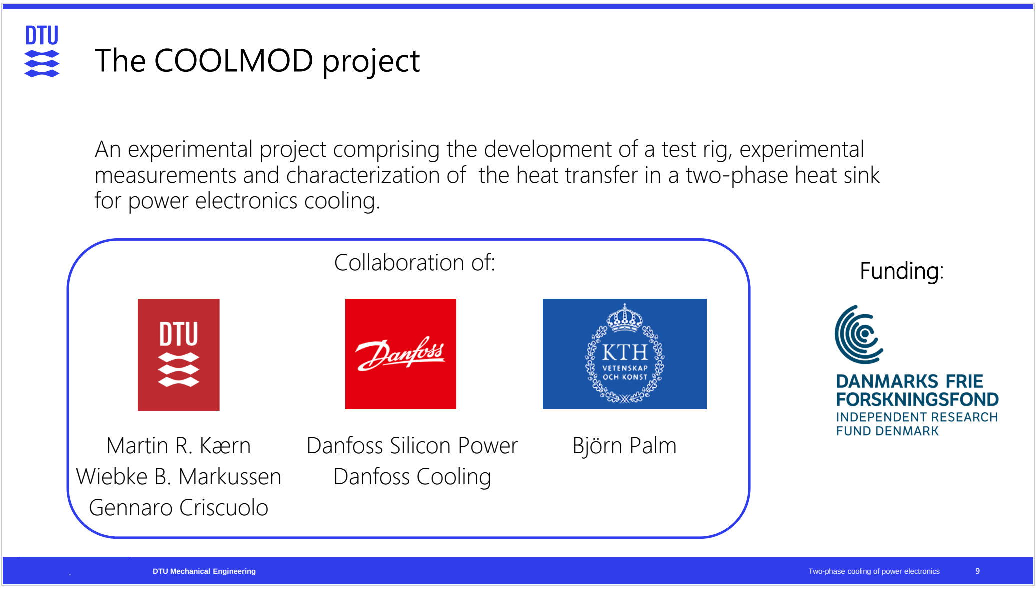
Two-phase cooling of power electronics


DTU
The COOLMOD project
An experimental project comprising the development of a test rig, experimental measurements and characterization of the heat transfer in a two-phase heat sink for power electronics cooling.
Collaboration of:
DTU
Danfoss
KTH VETENSKAP OCH KONST
Martin R. Kærn
Wiebke B. Markussen
Gennaro Criscuolo
Danfoss Silicon Power
Danfoss Cooling
Björn Palm
Funding:
DANMARKS FRIE FORSKNINGSFOND
INDEPENDENT RESEARCH FUND DENMARK
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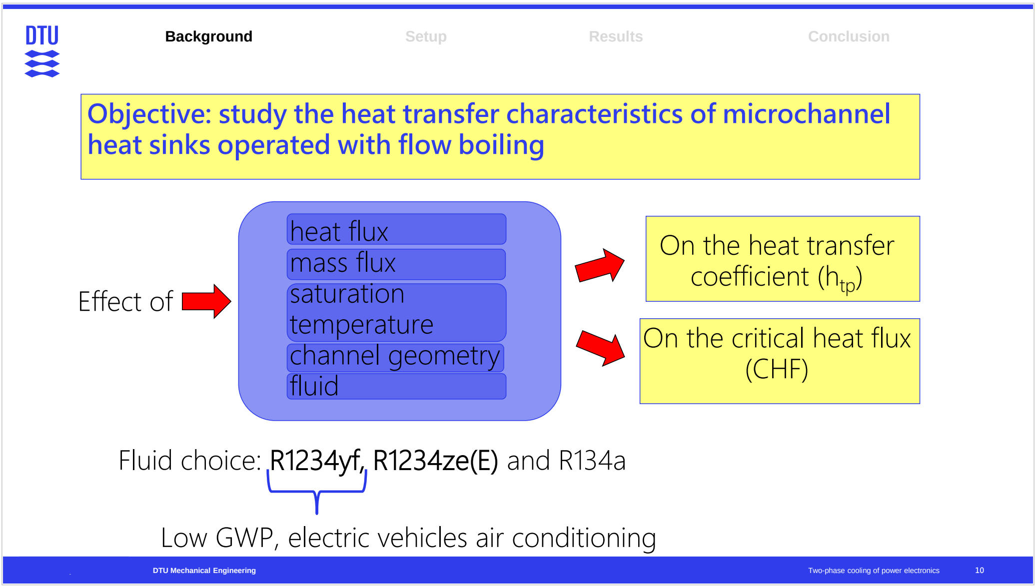
Two-phase cooling of power electronics
9


DTU
Background
Setup
Results
Conclusion
Objective: study the heat transfer characteristics of microchannel heat sinks operated with flow boiling
Effect of
heat flux
mass flux
saturation temperature
channel geometry
fluid
On the heat transfer coefficient (htp)
On the critical heat flux (CHF)
Fluid choice: R1234yf, R1234ze(E) and R134a
Low GWP, electric vehicles air conditioning
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Two-phase cooling of power electronics
10

Background Setup Results Conclusion

Complications in small-scale heat sinks

Bubble confinement

High heat fluxes

Channel interactions

Geometric tolerances

→ Instabilities

Cutting edge experimental equipment is needed:
- High speed camera
- Infrared camera
- Fully characterized test sections
- Well-controlled boundary conditions

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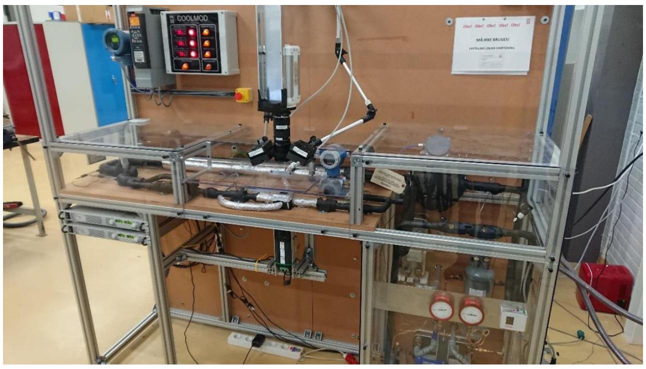
Experimental setup at DTU Mekanik



- Approx. 2,5 kg of refrigerant
- Operative pressure up to 11 bar in the test section
- Flow visualization in diabatic condition
- IR camera
- Up to 1500 W dissipation
- Suitable to flammable refrigerants

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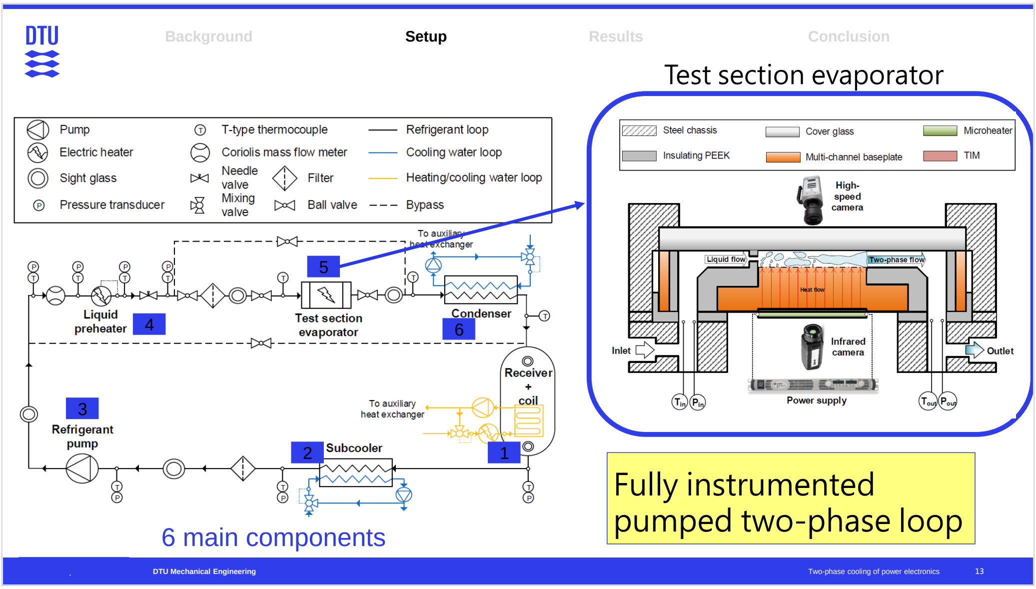
DTU
Background
Setup
Results
Conclusion
Test section evaporator
Pump
Electric heater
Sight glass
Pressure transducer
T-type thermocouple
Coriolis mass flow meter
Needle valve
Mixing valve
Filter
Ball valve
Refrigerant loop
Cooling water loop
Heating/cooling water loop
Bypass
Steel chassis
Insulating PEEK
Cover glass
Multi-channel baseplate
Microheater
TIM
High-speed camera
Liquid flow
Two-phase flow
Heat flow
Infrared camera
Power supply
Inlet
Outlet
To auxiliary heat exchanger
Liquid preheater
Test section evaporator
Condenser
Receiver + coil
Refrigerant pump
Subcooler
1
2
3
4
5
6
6 main components
Fully instrumented pumped two-phase loop
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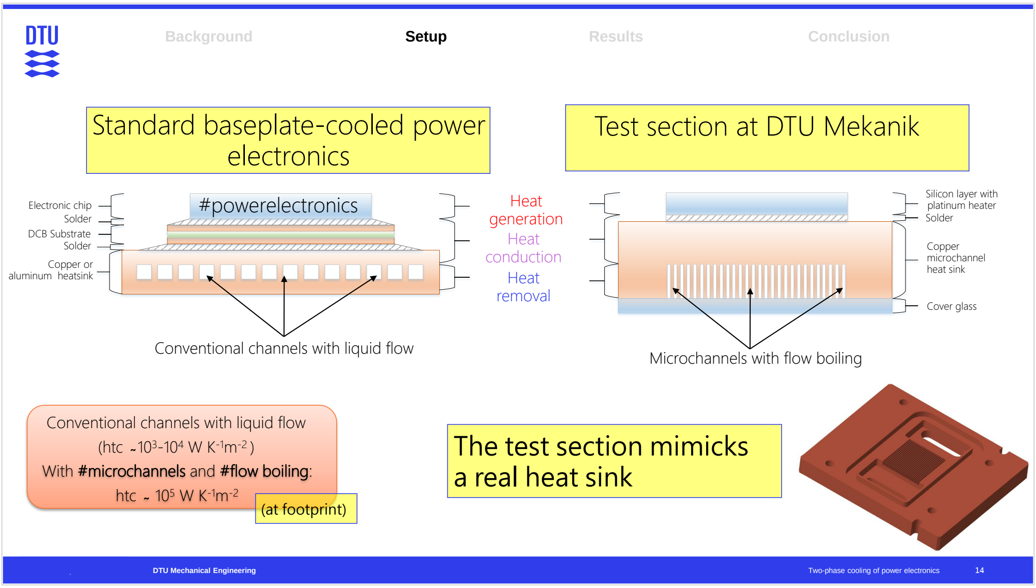
Two-phase cooling of power electronics
13


DTU
Background
Setup
Results
Conclusion
Standard baseplate-cooled power electronics
Test section at DTU Mekanik
#powerelectronics
Electronic chip
Solder
DCB Substrate
Solder
Copper or aluminum heatsink
Heat generation
Heat conduction
Heat removal
Silicon layer with platinum heater
Solder
Copper microchannel heat sink
Cover glass
Conventional channels with liquid flow
Microchannels with flow boiling
Conventional channels with liquid flow
(htc ~10³-10⁴ W K⁻¹m⁻²)
With #microchannels and #flow boiling:
htc ~ 10⁵ W K⁻¹m⁻²
(at footprint)
The test section mimicks a real heat sink
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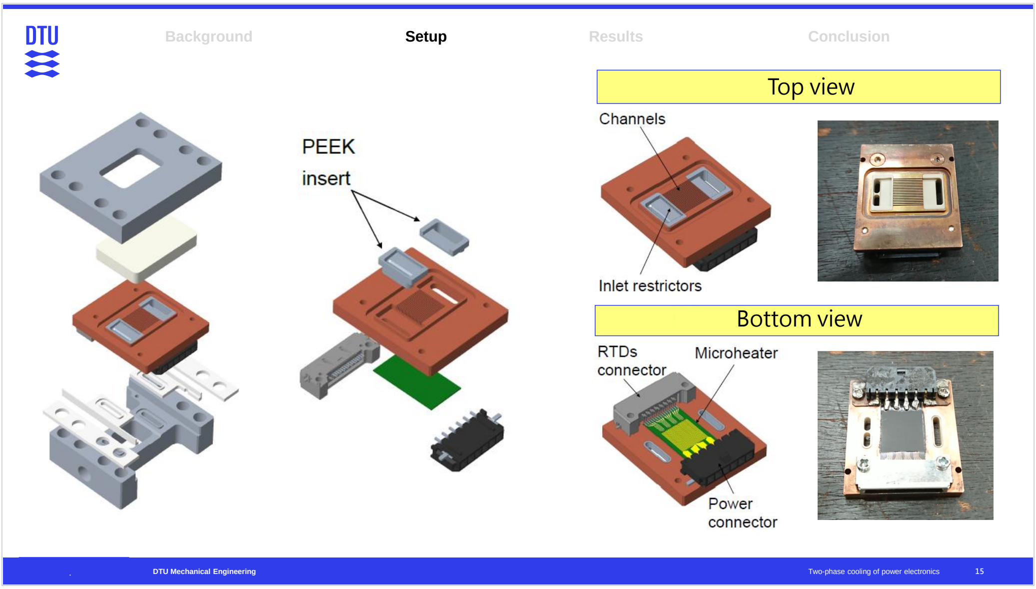
14


DTU
Background
Setup
Results
Conclusion
Top view
Channels
PEEK
insert
Inlet restrictors
Bottom view
RTDs
connector
Microheater
Power
connector
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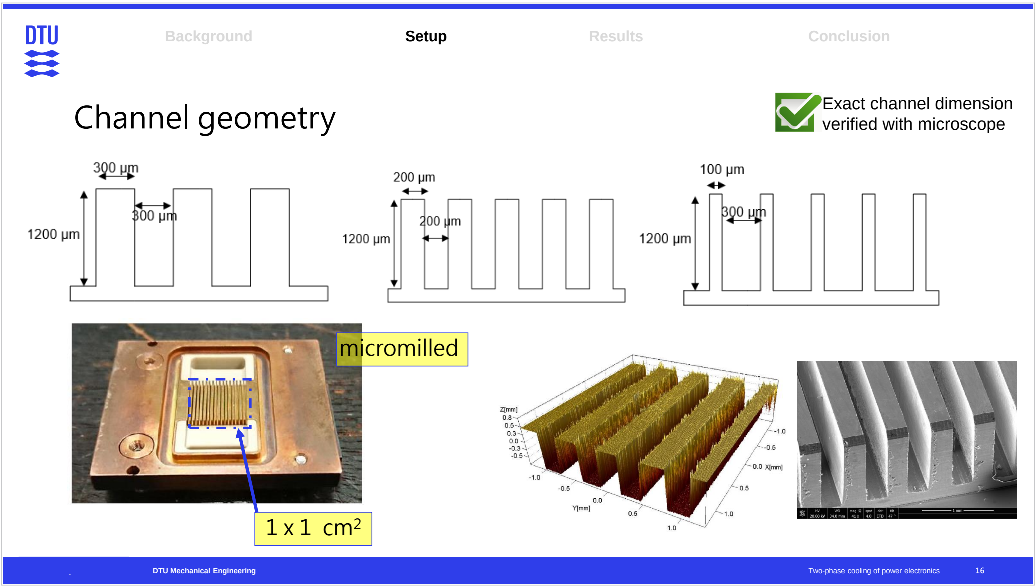
Two-phase cooling of power electronics
15


DTU
Background
Setup
Results
Conclusion
Channel geometry
Exact channel dimension
verified with microscope
300 µm
300 µm
1200 µm
200 µm
200 µm
1200 µm
100 µm
300 µm
1200 µm
micromilled
1 x 1 cm²
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16

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Results

- Microchannel heat sink: flow visualization and heat transfer characteristics
- Flow boiling heat transfer of R1234yf, R1234ze(E) and R134a
- Critical heat flux
- Data prediction

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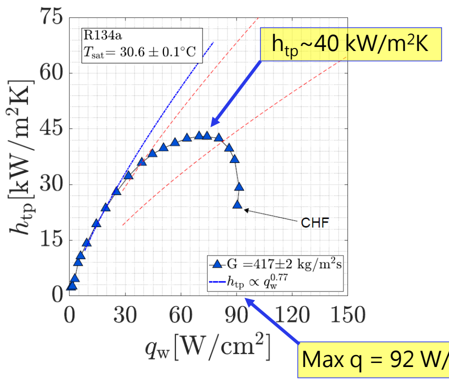
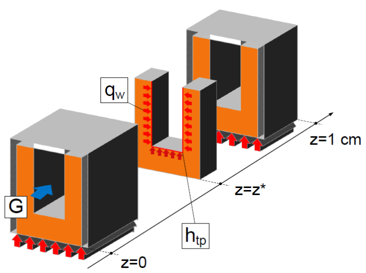
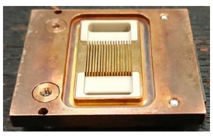
Background Setup **Results** Conclusion

Heat transfer characteristics and flow visualization







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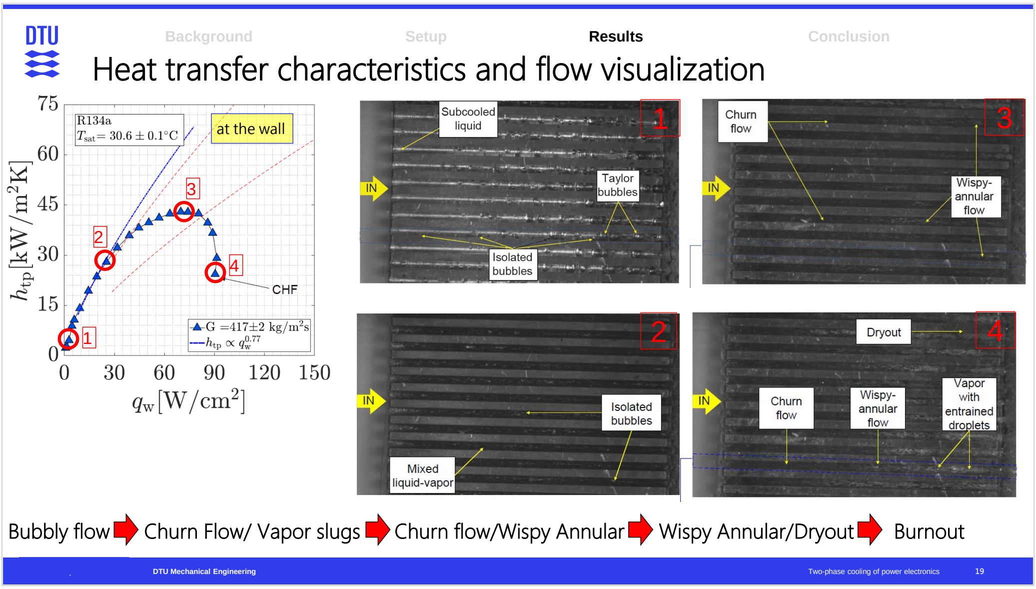
DTU
Background
Setup
Results
Conclusion
Heat transfer characteristics and flow visualization
R134a
$T_{sat} = 30.6 \pm 0.1$°C
at the wall
CHF
G =417±2 kg/m²s
$h_{tp} \propto q_w^{0.77}$
h_{tp} [kW/m²K]
q_w [W/cm²]
Subcooled liquid
Taylor bubbles
Isolated bubbles
Churn flow
Wispy-annular flow
Mixed liquid-vapor
Dryout
Vapor with entrained droplets
IN
Bubbly flow
Churn Flow/ Vapor slugs
Churn flow/Wispy Annular
Wispy Annular/Dryout
Burnout
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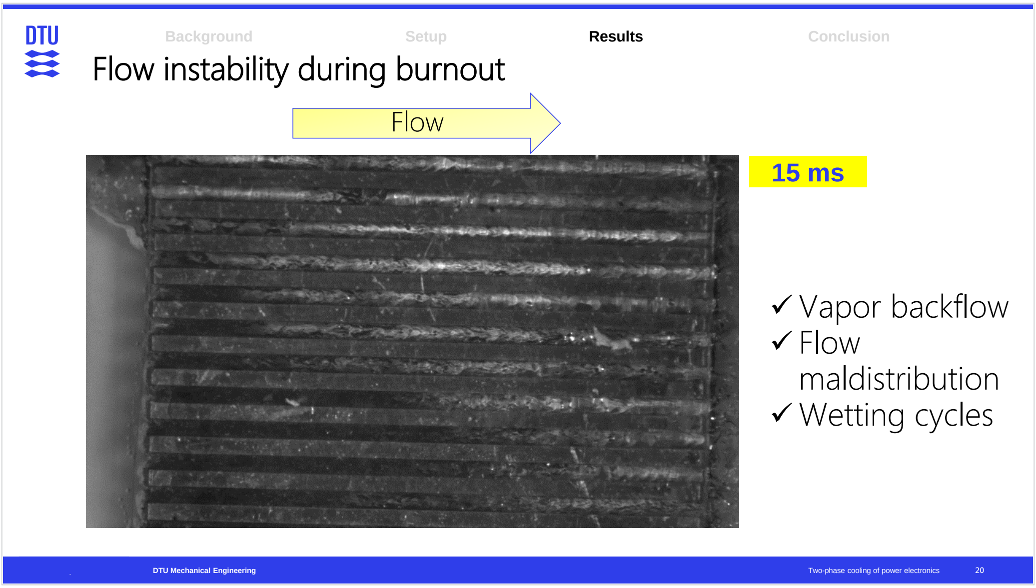
Two-phase cooling of power electronics
19


DTU
Background
Setup
Results
Conclusion
Flow instability during burnout
Flow
15 ms
✓ Vapor backflow
✓ Flow maldistribution
✓ Wetting cycles
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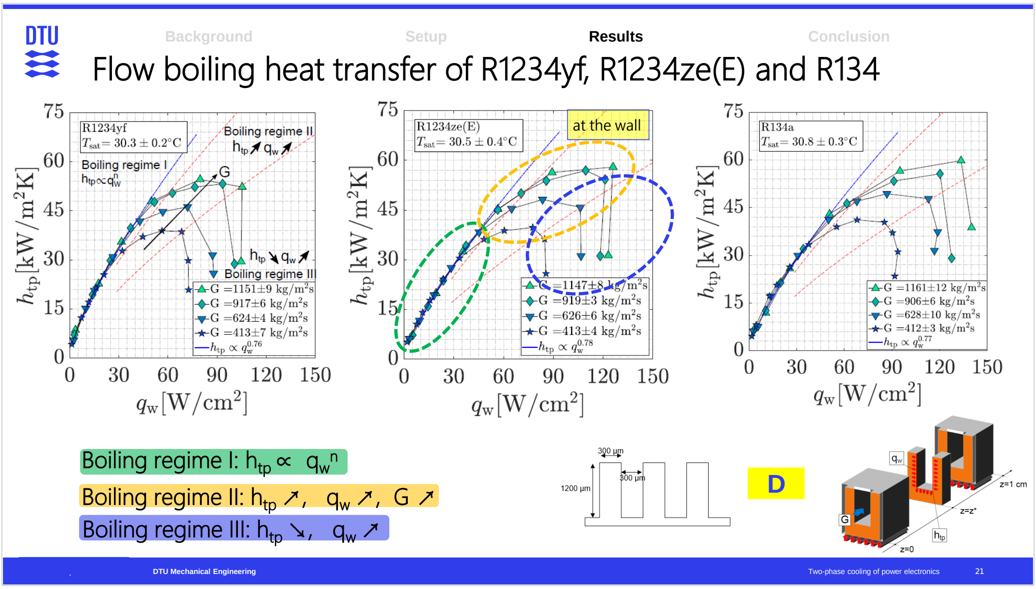
20



DTU
Background
Setup
Results
Conclusion
Flow boiling heat transfer of R1234yf, R1234ze(E) and R134
R1234yf
$T_{sat} = 30.3 \pm 0.2$°C
Boiling regime I
$h_{tp} \propto q_w^n$
Boiling regime II
Boiling regime III
$G = 1151 \pm 9$ kg/m²s
$G = 917 \pm 6$ kg/m²s
$G = 624 \pm 4$ kg/m²s
$G = 413 \pm 7$ kg/m²s
$h_{tp} \propto q_w^{0.76}$
R1234ze(E)
$T_{sat} = 30.5 \pm 0.4$°C
at the wall
$G = 1147 \pm 8$ kg/m²s
$G = 919 \pm 3$ kg/m²s
$G = 626 \pm 6$ kg/m²s
$G = 413 \pm 4$ kg/m²s
$h_{tp} \propto q_w^{0.78}$
R134a
$T_{sat} = 30.8 \pm 0.3$°C
$G = 1161 \pm 12$ kg/m²s
$G = 906 \pm 6$ kg/m²s
$G = 628 \pm 10$ kg/m²s
$G = 412 \pm 3$ kg/m²s
$h_{tp} \propto q_w^{0.77}$
h_{tp} [kW/m²K]
q_w [W/cm²]
Boiling regime I: $h_{tp} \propto q_w^n$
Boiling regime II: h_{tp} ↗, q_w ↗, G ↗
Boiling regime III: h_{tp} ↘, q_w ↗
300 µm
1200 µm
D
z=1 cm
z=0
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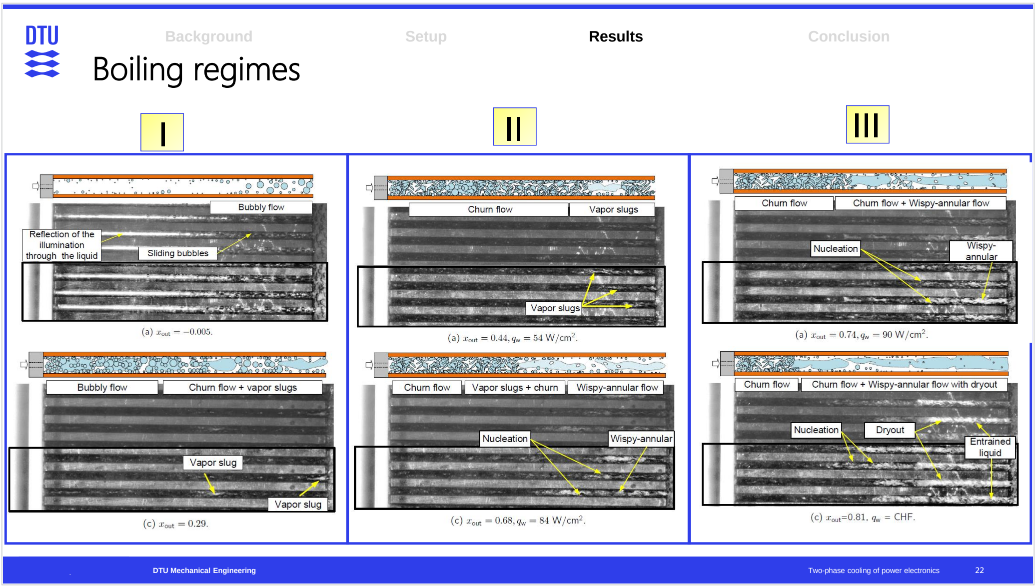
Two-phase cooling of power electronics
21



DTU
Background
Setup
Results
Conclusion
Boiling regimes
I
II
III
Bubbly flow
Reflection of the illumination through the liquid
Sliding bubbles
(a) $x_{out} = -0.005$.
Bubbly flow
Churn flow + vapor slugs
Vapor slug
Vapor slug
(c) $x_{out} = 0.29$.
Churn flow
Vapor slugs
Vapor slugs
(a) $x_{out} = 0.44$, $q_w = 54$ W/cm².
Churn flow
Vapor slugs + churn
Wispy-annular flow
Nucleation
Wispy-annular
(c) $x_{out} = 0.68$, $q_w = 84$ W/cm².
Churn flow
Churn flow + Wispy-annular flow
Nucleation
Wispy-annular
(a) $x_{out} = 0.74$, $q_w = 90$ W/cm².
Churn flow
Churn flow + Wispy-annular flow with dryout
Nucleation
Dryout
Entrained liquid
(c) x_{out}=0.81, q_w = CHF.
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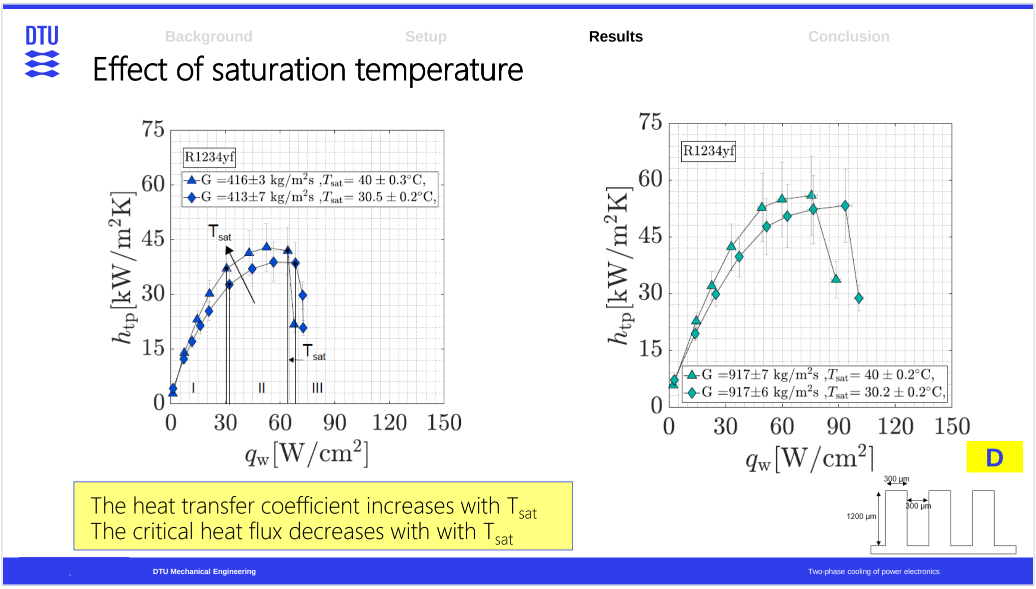
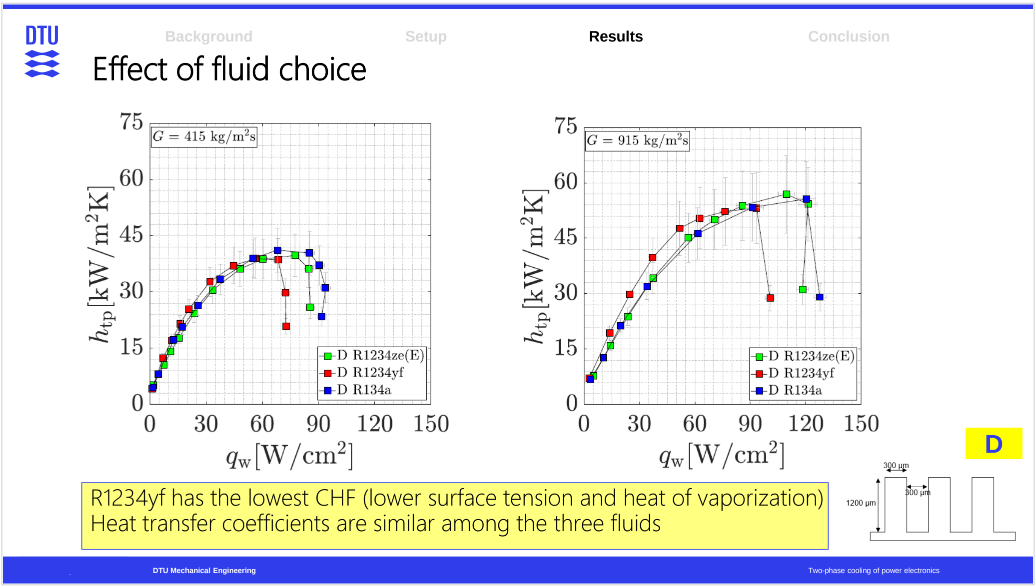
Two-phase cooling of power electronics
22


DTU
Background
Setup
Results
Conclusion
Effect of saturation temperature
R1234yf
G =416±3 kg/m²s , T_sat = 40 ± 0.3°C,
G =413±7 kg/m²s , T_sat = 30.5 ± 0.2°C,
T_sat
T_sat
I
II
III
h_tp [kW/m²K]
q_w [W/cm²]
R1234yf
G =917±7 kg/m²s , T_sat = 40 ± 0.2°C,
G =917±6 kg/m²s , T_sat = 30.2 ± 0.2°C,
D
The heat transfer coefficient increases with T_sat
The critical heat flux decreases with with T_sat
DTU Mechanical Engineering
Two-phase cooling of power electronics


DTU
Background
Setup
Results
Conclusion
Effect of fluid choice
G = 415 kg/m²s
D R1234ze(E)
D R1234yf
D R134a
h_tp [kW/m²K]
q_w [W/cm²]
G = 915 kg/m²s
D R1234ze(E)
D R1234yf
D R134a
D
R1234yf has the lowest CHF (lower surface tension and heat of vaporization)
Heat transfer coefficients are similar among the three fluids
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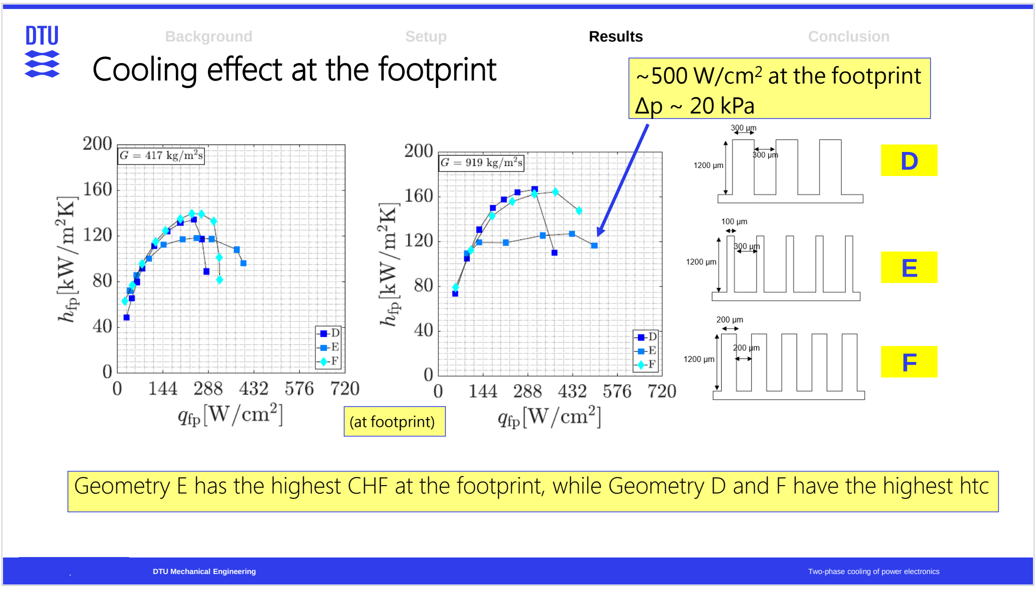
Two-phase cooling of power electronics


DTU
Background
Setup
Results
Conclusion
Cooling effect at the footprint
~500 W/cm² at the footprint
Δp ~ 20 kPa
G = 417 kg/m²s
G = 919 kg/m²s
(at footprint)
D
E
F
1200 µm
300 µm
100 µm
200 µm
Geometry E has the highest CHF at the footprint, while Geometry D and F have the highest htc
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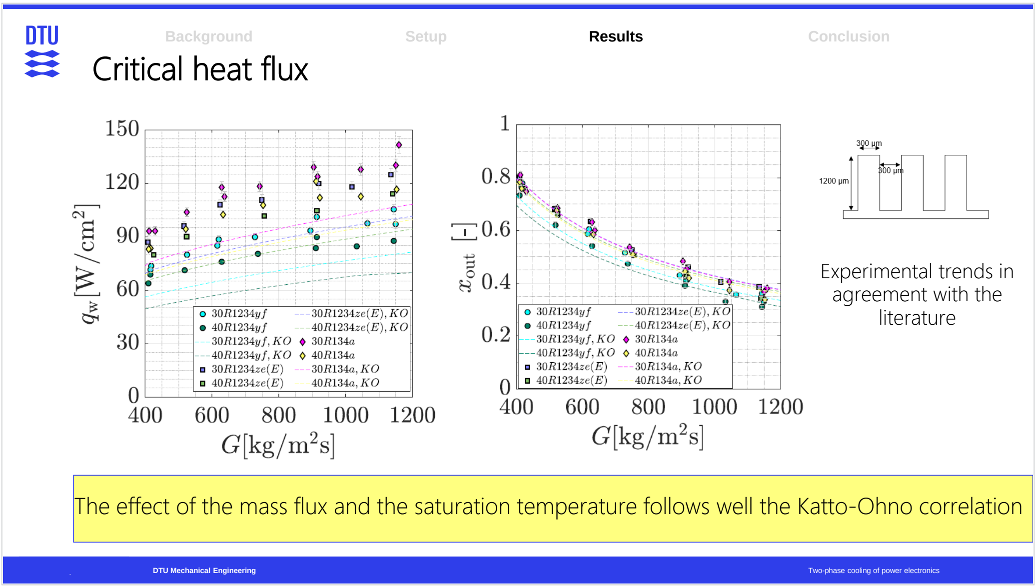
Two-phase cooling of power electronics


DTU
Background
Setup
Results
Conclusion
Critical heat flux
Experimental trends in agreement with the literature
1200 µm
300 µm
The effect of the mass flux and the saturation temperature follows well the Katto-Ohno correlation
DTU Mechanical Engineering
Two-phase cooling of power electronics

Background Setup **Results** Conclusion

Data prediction

Prediction of local heat transfer coefficients by coupling the literature correlations with a 1D fin model

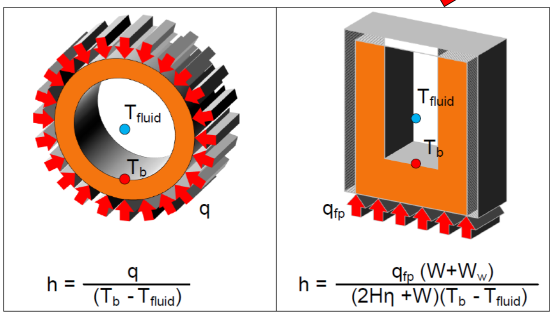
Asymmetric heating condition

$$h_{\text{corr}} = f_{\text{corr}}(q, \eta, \ldots)$$

$$m = \sqrt{\frac{2h_{\text{corr}}}{k \cdot W_{\text{wall}}}}$$

$$\eta = \frac{\tanh(mH)}{mH}$$

$$q = \frac{q_{\text{fp}} \cdot (W + W_{\text{wall}})}{(W + 2H\eta)}$$



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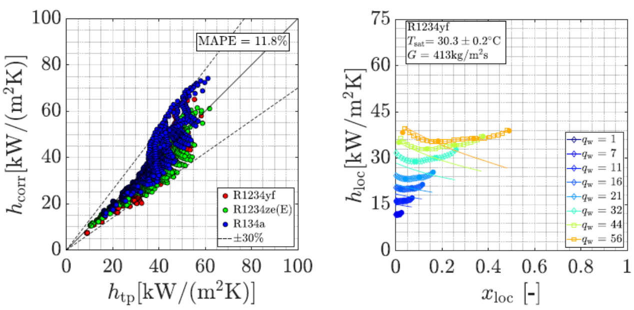

(a) Bertsch at al. [110]. (a) Bertsch at al. [110].

Statistical comparison of the data with the predictions of the correlation by Bertsch et al. - Flow-wise prediction fails to capture the U-shaped trend of h_{loc}

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Conclusion

- Novel experimental data on the flow boiling of R1234yf and R1234ze(E) in narrow multi-channel heat sinks at high heat fluxes were provided.
- Critical heat fluxes between 50 W/cm^2 and 120 W/cm^2 at the walls could be achieved in the investigated setup, which resulted in footprint heat dissipation between 250 W/cm^2 and 600 W/cm^2. This values are suitable to electronics cooling in electric vehicle.
- Three boiling regimes were identified as the heat flux was varied from low to CHF values. A gradual progression from a nucleate boiling condition to an unsteady regime with wispy-annular flow alternation with churn flow was observed. Dryout eventually occurs, resulting in wall temperature oscillation.
- The heat transfer coefficient could be predicted with the Bertsch et al. correlation for low vapour qualities. Flow-wise trends were not predicted.
- The effect of experimental parameters on the critical heat flux followed well the Katto-Ohno correlation.

DTU Mechanical Engineering — Two-phase cooling of power electronics — 29

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Thanks for your attention!

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DTU Mechanical Engineering — Two-phase cooling of power electronics — 30

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