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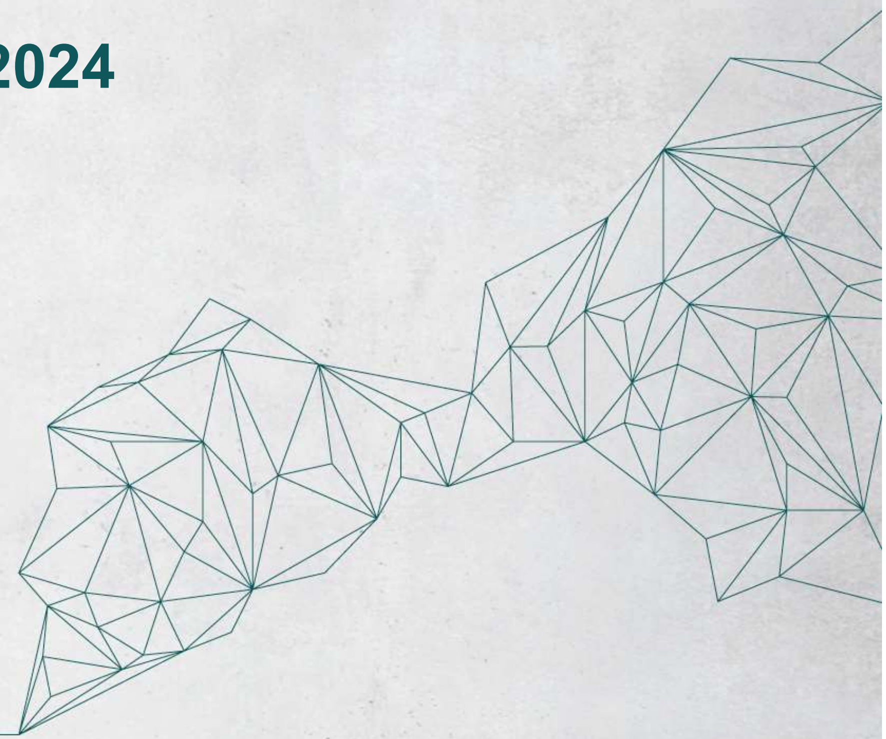

Energy efficient residential and commercial heat pumps for renovation buildings with low GWP HFO refrigerants

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Abstract

Heating and Cooling in buildings make about **40% of final energy consumption in the EU**. Most of this energy is still being provided by fossil fuel heating systems. Heat pumps are dedicated to being the leading technology for decarbonization and for electrification of heating. An average performing heat pump with a SCOP of 3.5 can save around **70% of CO2 emissions** compared to oil and gas boiler systems. For renovation buildings the requirements for a heating system are more challenging than for new buildings as usually a higher flow temperature is requested for the existing radiator system. Here, the energy efficiency is becoming even more important as it turns directly into energy consumption and indirect emissions during the whole system lifetime.

A thermodynamic model of a heat pump system has been developed by variation of several parameters; this model may help heat pump manufacturers designing high performing heat pumps for energy efficient operation. The model has been validated for **low GWP HFO** based refrigerant **Opteon™ XL20 (R-454C).** This presentation shows the thermodynamic model and the main settings influencing the performance of a heat pump system in terms of capacity and energy efficiency.

AGENDA

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Introduction

- *Europe's Choice* renewed *Green Deal t*arget: Reduction of net CO_2 emissions of 55% by 2030 versus 1990 emissions.
- Buildings Heating and Cooling using around 40% of EU total consumed energy.
- Heat Pumps play a key role in the decarbonization of residential and commercial heating (60 – 70% vs. Existing fossil fuel boilers).
- Air-to-Water Heat Pumps are required to efficiently operate also at low ambient temperature conditions.
- For buildings renovation, higher flow temperatures are required (≥ 55°C), also for heating purpose .
- **The requirements for A/W Heat Pumps for renovation buildings are the most challenging ones:**
  - **Efficient Operation at low ambient temperatures (down to -20°C)**
  - **High temperature-lift required (-30°C to +75°C)**

Background & Motivation for the XL20 Efficiency Project

- Opteon™ XL20 (R-454C) is an HFO based Low GWP refrigerant (GWP 148) offering high efficiency and higher temperature lift performance compared to avaialble alternatives.
- These conditions are requested by A/W Heat Pumps at low ambient temperatures, especially in buildings renovation with radiator heaters and for sanitary hot water production.
- Simple rotary compressors with wide operating envelope ($t_C \leq 65°C$ @ $t_{Ev} = -30°C$ / $t_C \leq 75°C$ @ $t_{Ev} \geq -10°C$) are commercially available on the market.
- Suppression of the need for additional electrical heaters. This leads to higher system efficiency and reliability.
- The study feature a thorical comparison on COP and Capacity vs. Alternative refrigerants, incl. R-290 (RefProp calculations on simple refrigerant circuit)
- Commercially available Heat Pumps based on Opteon™ XL20 (R-454C) feature up to 15% higher efficiency compared to R-410A systems.

Project Targets

- Define the optimization potential for Opteon™ XL20 (R-454C) in Heat Pumps.
- Identify system parameters with highest influence on Heat Pumps energy efficiency and capacity.
- Create a Simulation Tool that allows system optimization while minimizing testing and development cost and time to market.

Project Scope

XL20 Efficiency Project issued by an **Independent Research Institute** in Germany

- Laboratory Test Series
  - A: R-407C Reference with enhanced measurement equipment
  - B: R-454C Drop-In Reference
  - C1: R-454C + Compressor exchanged
  - C2: R-454C + adapted Superheat Control
  - D: R-454C + modified IHX (optimized by simulation)

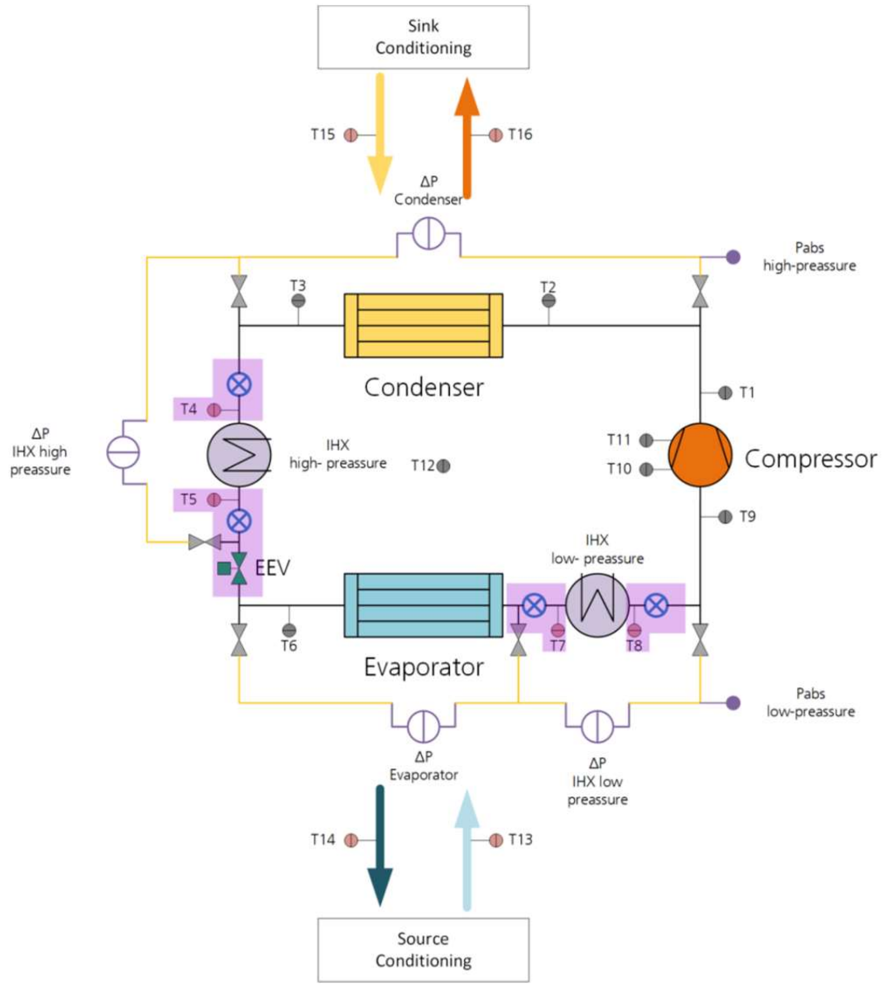
- Thermodynamic Model
  - Model creation
  - Model validation
  - Simulations

Modelica

Dymola

TIL suite

Refrigerant circuit of tested Heat Pump



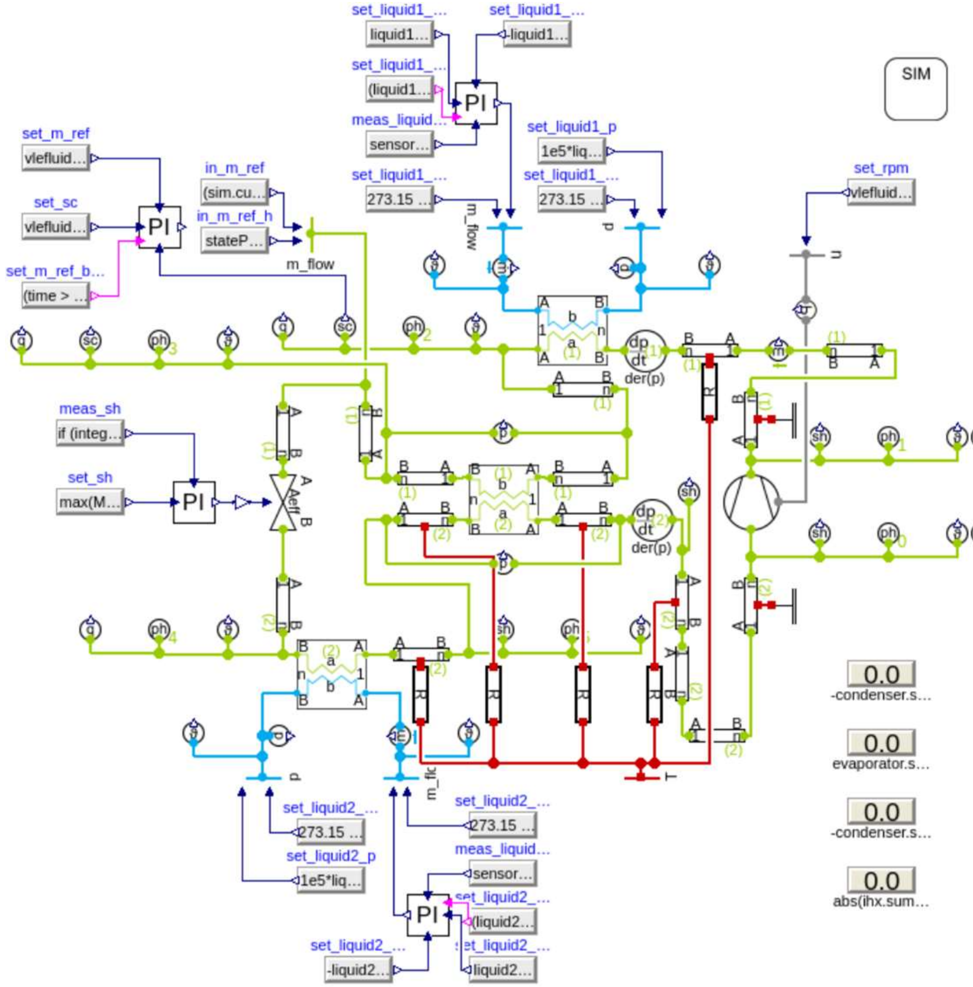
Legend

- sight glass
- copper pipe
- gomax flexible pipe
- components different from construction condition

T → temperature sensors,
grey → contact sensor
red → immersive sensor

T1 – compressor out
T2 – condenser in
T3 – condenser out
T4 – IHX high preassure in
T5 – IHX high preassure out
T6 – evaporator in
T7 – evaporator out / IHX low preassure in
T8 – IHX low preassure out
T9 – compressor in
T10- oil sump
T11- compressor surface
T12- air temperature inside the heatpump
T13- heat source inlet
T14- heat source outlet
T15- heat sink inlet
T16- heat sink outlet

Modelica model of the heat pump (test C)



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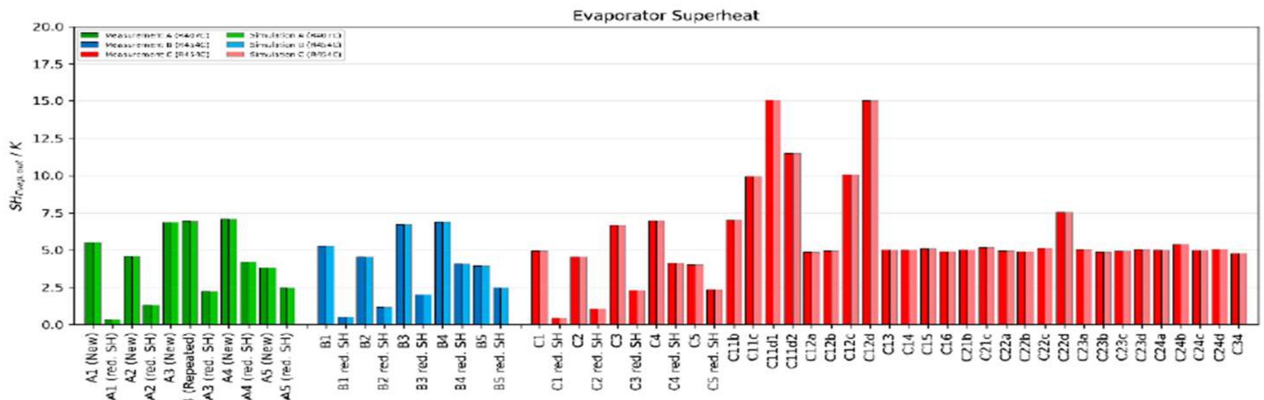
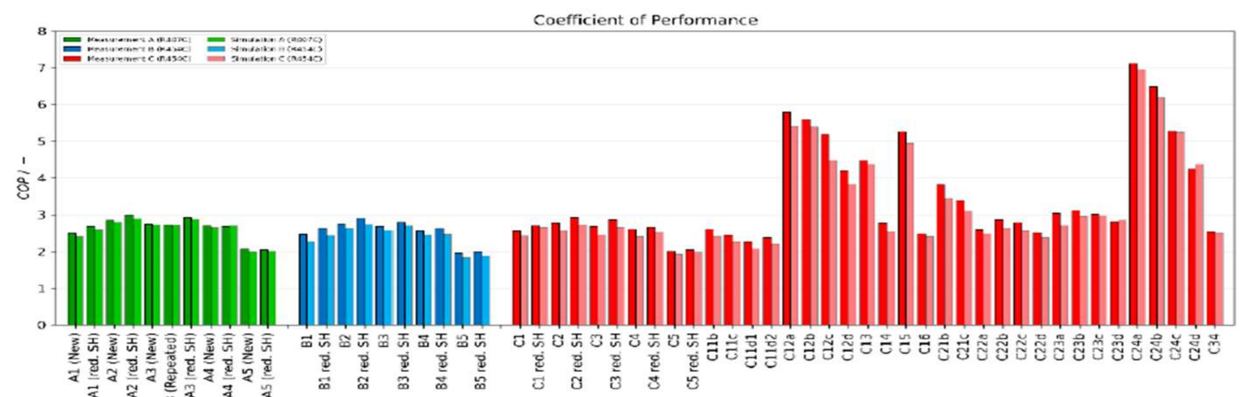
Simulation Results Comparison (model accuracy)

- Comparison of the experimental results with the simulation results of the Modelica model

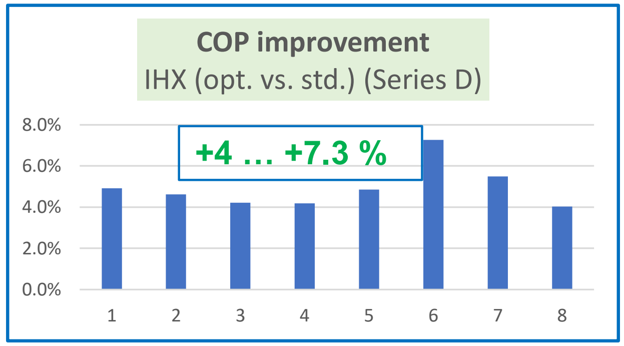


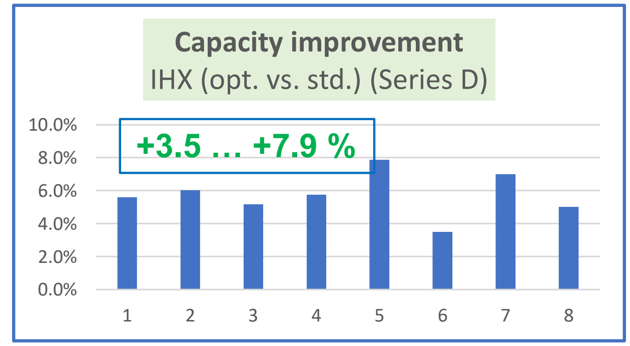


Note: Strong colors = measured values; light colors = simulations

Laboratory Test Results

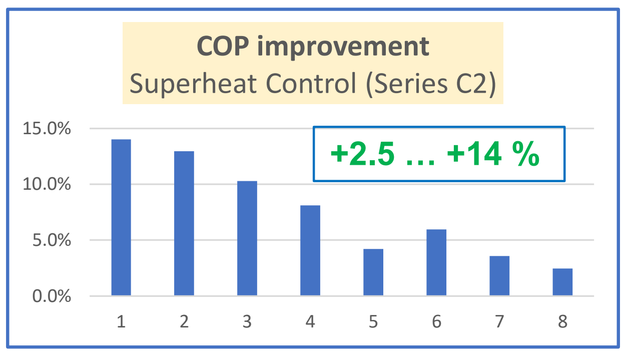
Improvements from **IHX**

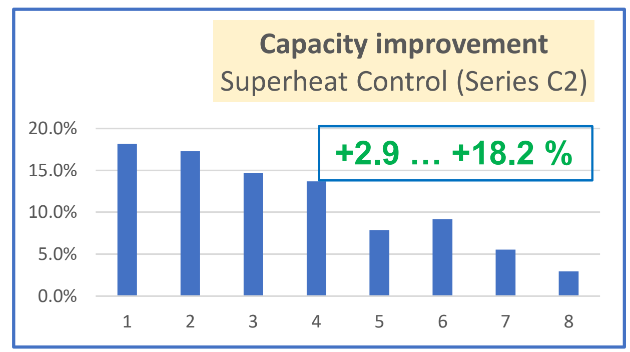




Improvements from

Superheat Control

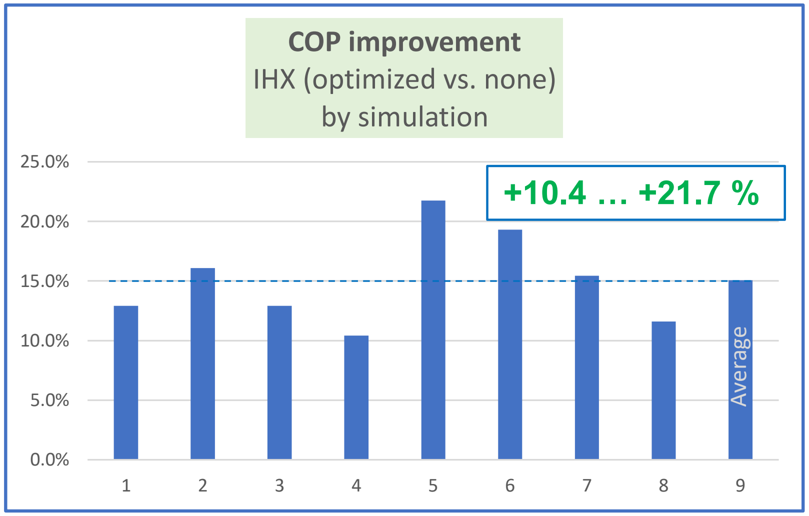


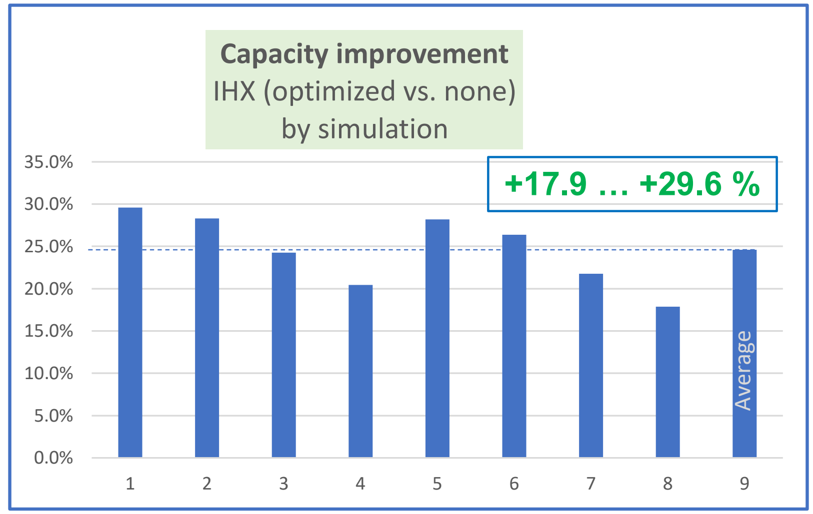


Legend	
1	B0/W55; 30Hz
2	B0/W55; 50Hz
3	B0/W55; 70Hz
4	B0/W55; 90Hz
5	B0/W35; 30Hz
6	B0/W35; 50Hz
7	B0/W35; 70Hz
8	B0/W35; 90Hz

Simulation Results

- Improvements from **IHX**





Legend	
1	B0/W55; 30Hz
2	B0/W55; 50Hz
3	B0/W55; 70Hz
4	B0/W55; 90Hz
5	B0/W35; 30Hz
6	B0/W35; 50Hz
7	B0/W35; 70Hz
8	B0/W35; 90Hz
9	Average

Results - Summary HP Application

Range of Improvements by Modification

Evaluated by	Modification	COP improvement (%)	capacity improvement (%)
measurement	Compressor	+0 ...+3	+0 ... +1
measurement	IHX	+4 ... +7	+4 ... +8
measurement	SuperHeat	+3 ... +14	+3 ... +18
simulation	IHX	+10 ... +22	+18 ... +30

Range of Improvements for all Modifications

Evaluated by	COP improvement (%)	capacity improvement (%)
measurement	+7 ... +24	+7 ... +27
measurement + simulation	+13 ... +39	+21 ... +49

- **The refrigerant circuit must be designed "around the refrigerant"!**
- **Double-digit improvements are possible with R-454C in COP and Capacity!**

View on the „Cold End“ (1)

- How to interpret the project results at the “Cold End” for ComRef Applications with XL20 (R-454C), GWP 148 ?

- The Operating Conditions are very similar to those in NT Cooling!
  - B0/W35: $t_0 \leq -5°C$, $t_C = 40°C$
  - B0/W55: $t_0 \leq -5°C$, $t_C = 60°C$
  - Compressor-Frequencies: 30, 50, 70, 90 Hz

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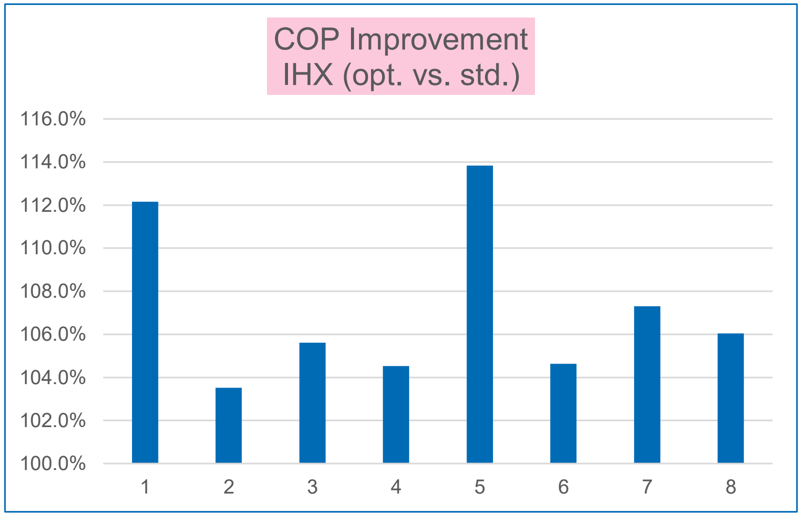
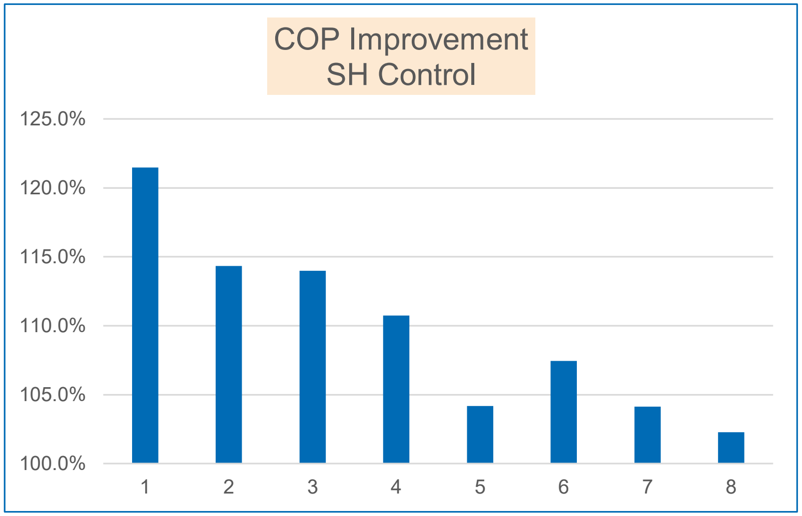
View on the „Cold End"(2)

Legend	
1	B0/W55; 30Hz
2	B0/W55; 50Hz
3	B0/W55; 70Hz
4	B0/W55; 90Hz
5	B0/W35; 30Hz
6	B0/W35; 50Hz
7	B0/W35; 70Hz
8	B0/W35; 90Hz

- Improvement of Efficiency (COP_C):





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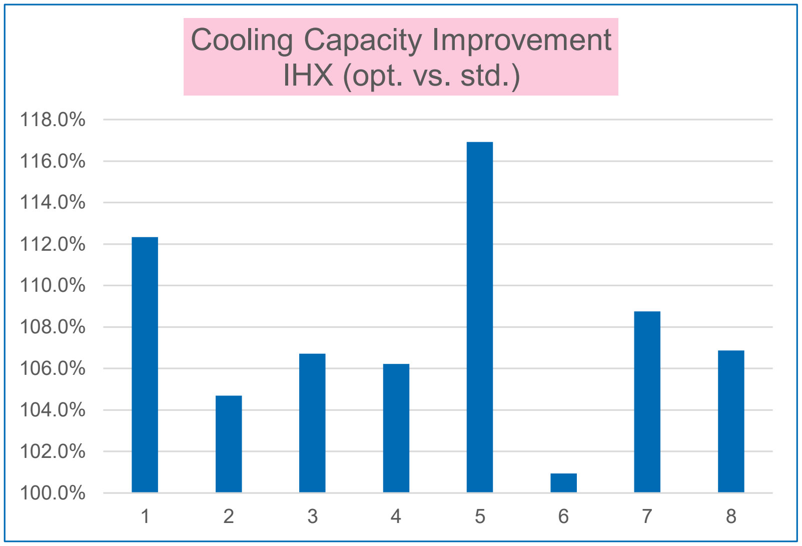
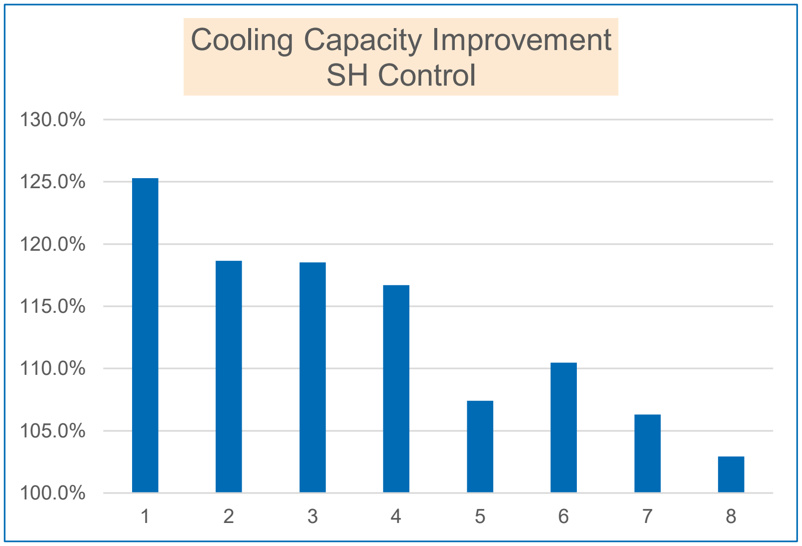
View on the „Cold End“ (3)

Legend	
1	B0/W55; 30Hz
2	B0/W55; 50Hz
3	B0/W55; 70Hz
4	B0/W55; 90Hz
5	B0/W35; 30Hz
6	B0/W35; 50Hz
7	B0/W35; 70Hz
8	B0/W35; 90Hz

➢ Improvement of Cooling Capacity:





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View on the „Cold End“ (4)

- Optimization Results:

Determined by	Parameter	COP Improvement (%)	Cooling Capacity Improvement (%)
Measurement	Compressor	+0 …+6.5	+0 … +4.6
Measurement	IHX opt. vs. IHX std.	+4 … +14	+1 … +17
Measurement	SH control	+2 … +22	+3 … +25
Measurement	IHX + SH Control	+6 ... +36	+4 ... +42

- Huge Efficiency- and Capacity- Improvements possible!

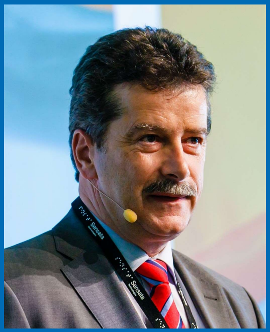
The Refrigerant Circuit has to be designed according to the Refrigerant!

Summary and Outlook

- The Test and Simulation Results are very promising:
  - Improvements in COP: HP: +7 … + 39% ComRef: +6 … + 36%
  - Improvements in Capacitiy: HP: +7 … + 49% ComRef: +4 … + 42%
- Opteon™ XL20 (R-454C) is a promising refrigerant candidate
  - for residential and commercial **Heat Pump applications**,
  - especially in renovation buildings,
  - requiring higher temperature lift (esp. A/W Heat Pumps)
  - For **Commercial Refrigeration applications**
- The Modelica Simulation Tool
  - enables reduction in laboratory testing time and
  - helps saving R&D cost

The Simulation Tool is available!

THANK YOU FOR YOUR KIND ATTENTION



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