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Low-GWP HFO Refrigerants Enabling Higher Energy Efficiency Heat Pumps

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Opteon™ XL20 (R-454C) thermodynamic and safety profiles make it highly suitable for residential and commercial HP deployments in building renovation and new buildings. A multi-year study presented at JRAIA Symposium outlines how specific equipment optimization measures can enable high energy efficiency gains and capacity improvements vs alternatives.

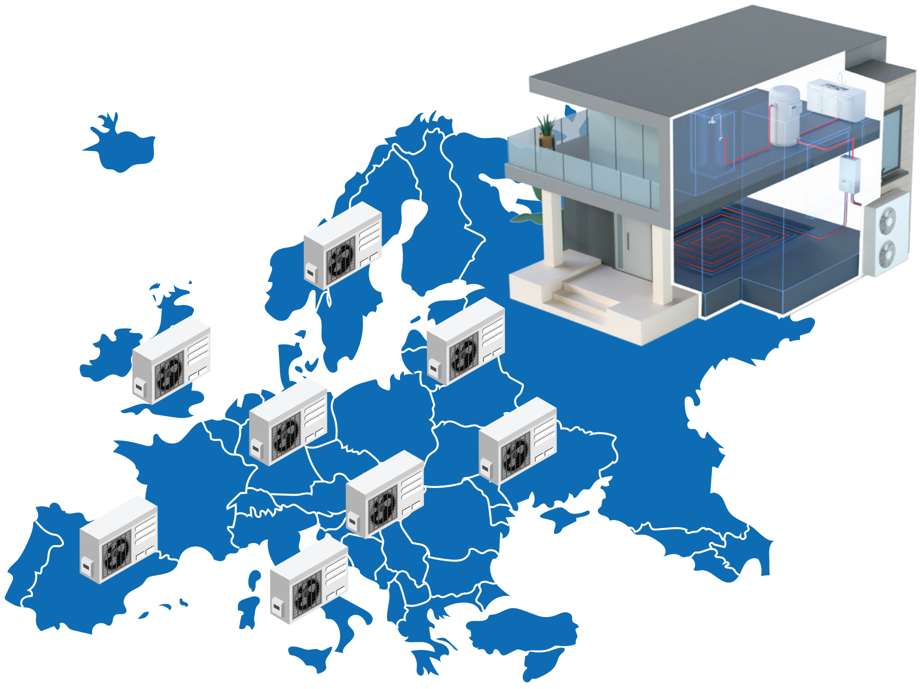
Introduction

In the European Union, heating and cooling in buildings account for a significant 40% of total energy consumption, a sector still predominantly powered by fossil fuels. Heat pumps emerge as the vanguard as we shift towards decarbonized, electrified heating.

Notably, an average heat pump, with a seasonal coefficient of performance (SCOP) of 3.5, can slash CO_2 emissions by about 70% compared to traditional oil and gas boilers. This is particularly crucial in renovating existing buildings, where integrating efficient heating systems poses unique challenges.

Background and Motivation

Opteon™ XL20 (R-454C) has emerged as a notable refrigerant in the industry, particularly for its performance in higher temperature lifts. This mildly flammable (A2L flammability class) hydrofluoroolefin (HFO) based refrigerant, with a low global warming potential (GWP) of 148, is proving to be effective in specific conditions, especially in air-to-water (A/W) heat pumps operating at low ambient temperatures.



Due to these unique characteristics, heat pumps equipped with Opteon™ XL20 are frequently chosen for renovation applications that allow maintaining existing radiator heater and include sanitary hot water preparation.

One of the key advantages of Opteon™ XL20 is its compatibility with simple rotary compressors with a wide operating envelope. These compressors are capable of handling temperatures up to 65 °C at an evaporator temperature of -30 °C and up to 75 °C at an evaporator temperature of -10 °C or higher. They are readily available in the commercial market.

These operating conditions allow domestic heating system design to exclude hybrid configurations with additional electric heaters, leading to a reduction in equipment complexity and energy consumption and, ultimately, increased system efficiency.

This advantage is more pronounced when comparing the theoretical coefficient of performance (COP) and capacity of Opteon™ XL20 with other refrigerants, such as R-290, based on reference fluid properties (REFPROP) calculations on a simple refrigerant circuit. This adds up to the easier system design and installation practices related to the lower flammability rating of this refrigerant.

Commercially, heat pumps utilizing Opteon™ XL20 (R-454C) have achieved up to **15% higher efficiency compared to systems using R-410A ,** today representing one of the standard HFC solutions broadly adopted for these applications. This enhancement in efficiency not only underscores the potential of Opteon™ XL20 in heat pump applications but also aligns with the growing demand for energy-efficient refrigeration solutions.

The **XL20 Efficiency Project** [1,2] conducted with an established testing institute using a simulation model, was crafted using Modelica programming language in the Dymola dynamic modeling laboratory environment. Validated with Opteon™ XL20 (R-454C) refrigerant, this model is reshaping how we design powerful, efficient heat pumps, particularly for systems needing to work under tighter thermal requirements, like those in renovated buildings.

In this paper, we explore how the choice of refrigerant and designing their pathways is vital for a heat pump's performance. Our extensive testing demonstrates the steps to boost energy efficiency, moving us towards a future where heat and water supply are more sustainable than ever.

Project Targets

Exploring the optimization potential for heat pumps using Opteon™ XL20 (R-454C) involves a multifaceted approach. It's essential first to identify the system parameters that exert a major influence on the energy efficiency and capacity of the heat pump. These parameters determine the overall performance and effectiveness of the heat pump in various environments.

The idea of creating a simulation tool was introduced to streamline this process. This tool would facilitate system optimization by simulating different scenarios and conditions, reducing the need for extensive laboratory testing. Not only would this approach significantly cut down on development time, but it would also be cost-effective.

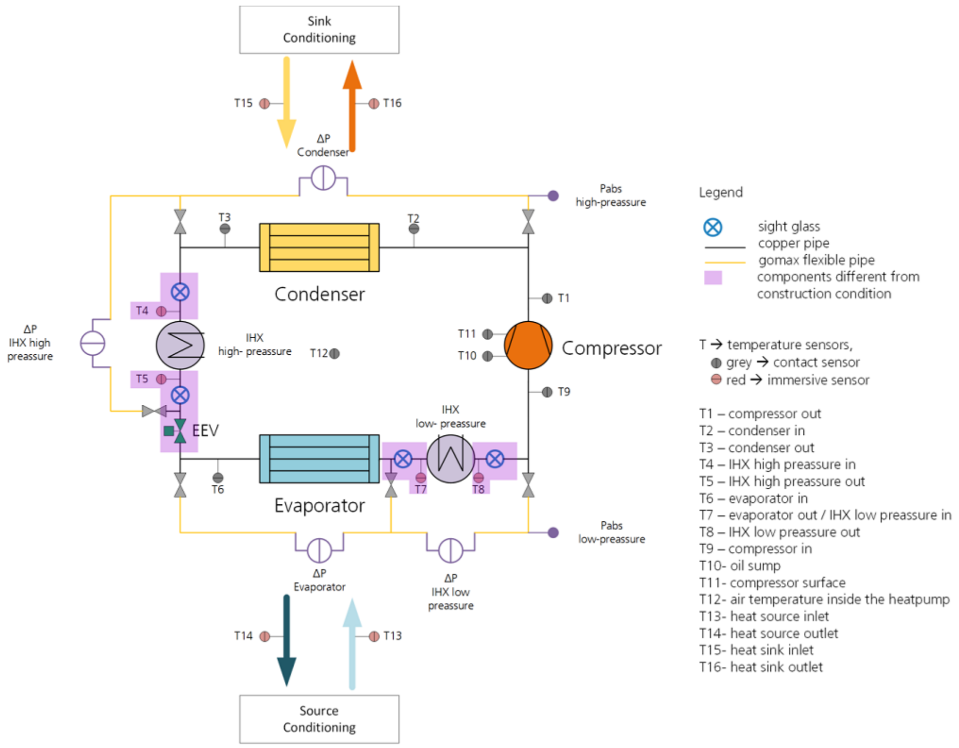
The tool's ability to model and predict system performance under varying conditions is important for enhancing the efficiency of heat pumps using Opteon™ XL20 (R-454C), ultimately leading to more sustainable and economically viable heating solutions.

Project Scope

The XL20 Efficiency Project, undertaken at a recognized institute specializing in energy analysis in Germany, represents a significant stride in refrigerant efficiency research. The project's core involved a series of comprehensive laboratory tests, each designed to evaluate different aspects of refrigerant performance under various conditions.

Each test series focused on a specific refrigerant and certain conditions:

- Series A used R-407C, a commonly used HFC refrigerant, and was conducted with enhanced measurement equipment to ensure precision.
- Series B was designed as a drop-in reference for R-454C, a reference refrigerant known for its low global warming potential.
- Series C consisted of two separate experiments:
  - C1 involved replacing the compressor with R-454C.
  - C2 incorporated an adapted superheat control with the same refrigerant.
- Finally, Series D examined the performance of R-454C in combination with a modified internal heat exchanger (IHX), which was optimized based on simulation results.



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Parallel to these tests, a comprehensive thermodynamic model was developed and validated. This model simulated various operating conditions to predict the performance of the refrigerants in different scenarios. These simulations were integral in testing and validating the laboratory experiments.

The laboratory test conditions were meticulously varied to examine the refrigerants' performance under different scenarios.

- **Conditions** included B0/W55 at frequencies of 30, 50, 70, and 90 Hz for all series, with additional conditions in Series C2 and D, such as B0/W35, and adaptations like the modified IHX as per simulation results.
- **Refrigerant types** varied across the series, with Series A using R-407C and Series B to D employing R-454C.
- Moreover, **additional conditions** were included for model validation, encompassing air-to-water (A/W) conditions, furthering the project's scope in understanding refrigerant efficiency in diverse operational contexts.

This comprehensive approach in the XL20 Efficiency Project highlighted the potential of different refrigerants in varied settings and set a benchmark in refrigerant efficiency testing and modeling. The project's findings are expected to significantly influence future refrigerant technology and heat pump system developments.

Summary Results

The test and simulation results of the project involving Opteon™ XL20 (R-454C) as a refrigerant in residential heat pump applications have yielded very promising outcomes.

Range of Improvements by Modification

Evaluated by	Modification	COP improvement (%)	Capacity improvement (%)
Measurement	Compressor	+0 ...+3	+0 ...+1
Measurement	IHX optimization	+4 ...+7	+4 ...+8
Measurement	SuperHeat	+3 ...+14	+3 ...+18
Simulation	IHX optimization	+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

Coefficient of performance (COP) improvements ranged from a notable 7% to an impressive 39%, while capacity increases varied between 7% and 49%. This data highlights Opteon™ XL20 efficacy, especially in retrofit buildings where advanced temperature lift capabilities, such as in air-to-water (A/W) heat pumps, are required.

Using the Modelica Simulation Tool was a standout feature of the project. This cutting-edge tool played a pivotal role in speeding up the development process by reducing the need for extensive laboratory testing, thereby leading to significant cost savings in research and development. This breakthrough is instrumental in propelling refrigerant and heat pump technology forward.

One key takeaway is the profound impact of customizing the refrigerant circuit to match the specific properties of Opteon™ XL20 (R-454C). By tailoring systems to exploit the unique characteristics of R-454C, we observed notable enhancements in both COP and capacity. This strategy is essential for creating more efficient, cost-effective, and sustainable heating solutions for residential settings.

Outlook for Heat Pump Efficiency

In summary, this third party independent research on Opteon™ XL20 (R-454C) conducted by this recognized German institute represents a significant milestone in sustainable heating technology. This study confirms the high potential of low GWP HFO refrigerants like R-454C for residential heat pump applications, particularly in renovation contexts requiring high-temperature lifts.

The project's success in achieving notable performance improvements through systematic testing and simulations paves the way for future advancements in heat pump efficiency.

This study serves as a guiding framework for future heat pump technology, highlighting the critical role of innovative solutions and collaborative research in addressing the challenges of energy efficiency and environmental sustainability. The insights and methodologies developed here lay a solid foundation for the next generation of heat pump systems, contributing significantly to the global effort to reduce carbon emissions and achieve a more sustainable future.

If you would like to discuss low-GWP refrigerant solutions for heat pump designs and systems for any installation, contact our team: hans-dieter.kupper@chemours.com

References

1. Fraunhofer Institute for Solar Energy Systems, ISE. (2023). Chemours R-454C, Analysis and optimization of an R-407C brine-to-water heat pump for the usage with R-454C (Report No. AN21-1044).
2. Küpper, H.-D. (2023). Energy efficient residential and commercial heat pumps for renovation buildings with low GWP HFO refrigerants. Paper presented at JRAIA Kobe Symposium.