Opteon™

Driving Energy Efficiency in U.S. Supermarkets:
A2L Refrigerants in Commercial Refrigeration

Chemours™

Opteon™ XL20 (R-454C), Opteon™ XP40 (R-449A), and CO_2 (R-744) refrigerants offer distinct thermodynamic and environmental profiles that impact their suitability for next-generation commercial food retail refrigeration.

A comprehensive study comparing these low-GWP refrigerants demonstrates how careful selection and smart system design can deliver significant energy efficiency improvements and operational advantages across a range of supermarket applications and climates.

Introduction

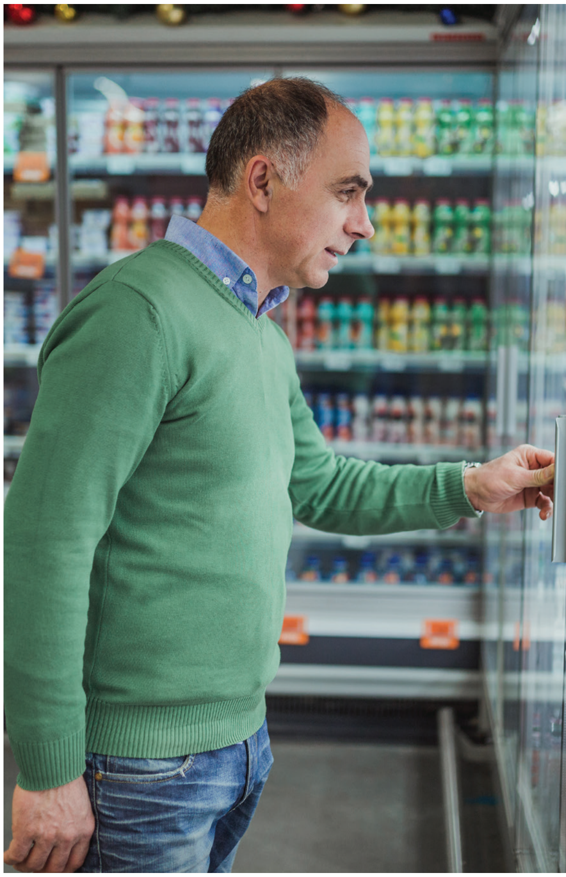
Refrigeration is the lifeblood of supermarkets and grocery stores – accounting for up to 60% of their total energy consumption[1], making these businesses among the most energy-intensive in the commercial sector. As international efforts to combat climate change accelerate —driven by climate treaties like the Kyoto Protocol and Paris Agreement— refrigeration technology is facing increasing scrutiny.

The U.S. EPA's American Innovation and Manufacturing (AIM) Act outlines a schedule for the phasedown of hydrofluorocarbons (HFCs), which is already underway. The second part of the AIM Act, the Technology Transition Rule, also outlines requirements to use lower Global Warming Potential (GWP) refrigerants in new equipment in retail food refrigeration, for both remote condensing units and supermarket systems.

Transitioning from high-global warming potential (GWP) refrigerants to lower-GWP alternatives is a proven strategy for reducing climate impact. However, to achieve meaningful and lasting progress, these efforts must be paired with improvements in energy efficiency. As the supermarket industry evolves, there is an urgent need for refrigeration solutions that are not only more sustainable but also cost-effective, reliable, and easy to maintain – across both new developments and existing stores.

Background and Motivation

Historically, hydrofluorocarbons (HFCs) like R-404A and R-507 were adopted to phase out ozone-depleting substances. However, as regulations evolved together with the scientific understanding of the global warming process— most recently via the US AIM Act and Kigali Amendment to the Montreal Protocol—attention turned to refrigerants with both low ozone depletion potential and low GWP.



Two classes have emerged:

- Hydrofluoroolefin (HFO) based blends such as Opteon™ XL20 (R-454C, GWP 148) and Opteon™ XP40 (R-449A, GWP 1397), which are designed to closely match performance of legacy HFC's with minimal changes to system architecture.
- Non-fluorinated refrigerants such as carbon dioxide (R-744, GWP 1), which offer ultra-low GWP but may require more complex and costly system designs, especially for warm ambient climates.

Operators, engineers, and sustainability leaders need evidence-based guidance on which technologies deliver the best combination of environmental performance, operational reliability, and cost efficiency.

Project Scope

A comprehensive thermodynamic analysis was conducted to compare the performance of three leading low-GWP refrigerants - R-454C, R-449A, and R-744 - in food retail refrigeration systems, using a real supermarket layout as the testbed.

Key objectives:

- Quantify seasonal energy efficiency (sCOP) and annual energy consumption for each refrigerant and location.
- Evaluate system complexity, operational requirements, and maintenance implications.
- Provide practical recommendations for supermarket operators, consultants, and policy makers.

Methodology

System Modeling and Testing

The study utilized an advanced semi-analytical model to simulate supermarket refrigeration layouts, validated with real-world component data from manufacturer selection software. The systems assessed included:

- **Opteon™ XL20 (R-454C)** and **Opteon™ XP40 (R-449A)**: Standard vapor compression cycles (VCC), basic form modified to include a Liquid Line-Suction Line Heat Exchanger (LL-SLHX). (Fig.1)
- **R-744 (CO_2)**: State-of-the-art parallel compression system, with flash gas bypass and liquid line–suction line heat exchangers (LL-SLHX), supporting both subcritical and transcritical operation depending on ambient temperature. (Fig. 2)

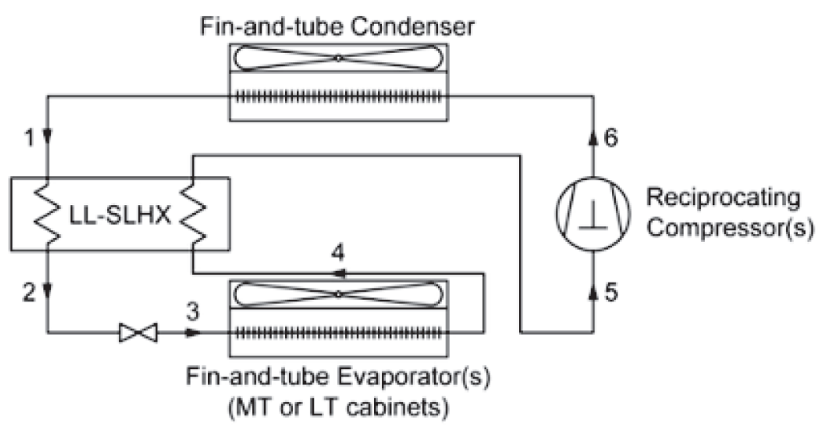


Figure 1: Vapor compression cycle with a LL-SLHX

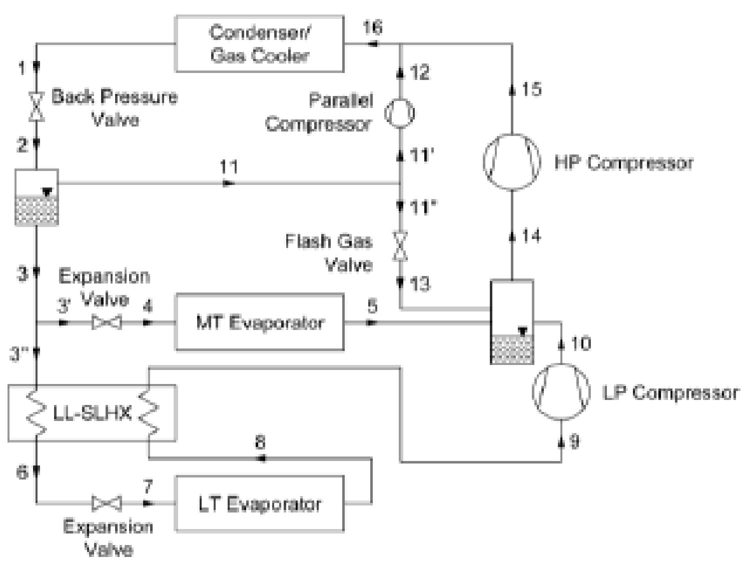


Figure 2: Transcritcal CO_2 booster with parallel compression

To calculate energy efficiency and sCOP, temperature profiles were defined in each climate zone based on hourly bin data (Figure 3). Evaporator temperatures and circuit loads are defined in Table 1 and are meant to represent a typical load for a large supermarket.

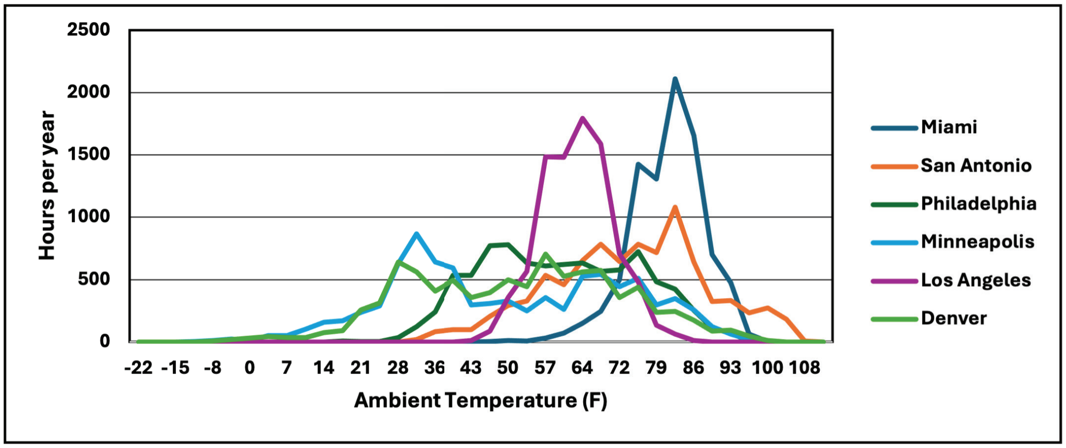


Figure 3: Hourly temperature bins

Table 1. Design evaporator temperature and refrigerated load

Cooling Section	Evaporator Temperature [°F]	Load [kW]
Medium Temperature 1	20	143.8
Medium Temperature 2	18	144.2
Low Temperature	-20	80.5

Results and Discussion

Energy Efficiency and Consumption

The comparative analysis of Opteon™ XL20 (R-454C), Opteon™ XP40 (R-449A) and CO_2 (R-744) systems across a variety of climate conditions reveals a clear trend in favor of the HFO blends, particularly as ambient temperatures increase. Notably, in Miami – a representative city in a hot climate – systems using Opteon™ XP40 (R-449A) achieved up to a 14% improvement of sCOP over CO_2, while Opteon™ XL20 (R-454C) systems offered a 10% sCOP increase over CO_2

These efficiency gains carry significant implications for end users. Lower energy consumption translates directly into reduced electricity costs, improving the cost-effectiveness of refrigeration systems over their operational lifetime. Additionally, lowering energy demand results in decreased indirect greenhouse gas emissions, particularly in markets where electricity is primarily generated from fossil fuels. This dual benefit not only supports sustainability objectives but also strengthens the economic rationale for choosing HFO blends over traditional refrigerants.

System Complexity and Maintenance

An important consideration for system owners and operators is the complexity and maintainability of refrigeration installations. Opteon™ XL20 (R-454C) and Opteon™ XP40 (R-449A) systems offer substantial advantages in this regard. Opteon™ XP40 (R-449A) is a very close performance match to R-404A and R-22 allowing for the retrofit of existing infrastructure with minimal system modifications. This simplifies the upgrade process and limits the need for significant capital investment or extended system downtime. For new installations, both Opteon™ XP40 (R-449A) and Opteon™ XL20 (R-454C) can be readily integrated into conventional architectures, making the transition to lower-GWP alternatives straightforward for operators.

In contrast, CO_2 (R-744) systems present more inherent complexity, particularly in warmer climates. To maintain efficiency at elevated external air temperatures, advanced features such as parallel compression, adiabatic condensers, and flash gas management are typically required. These engineering solutions help address the thermodynamic challenges CO_2 faces above its critical point but add to both the initial installation cost and ongoing operational complexity. The requirement for specialized technician training and the increased likelihood of more frequent or specialized maintenance interventions can further contribute to the total cost of ownership, especially in regions prone to high temperatures.

Climatic Sensitivity

The sensitivity of refrigeration system performance to surrounding temperature is a crucial factor in selecting appropriate technologies for specific regions. CO_2-based systems demonstrate a pronounced decline in relative energy efficiency as the ambient temperature increases, largely due to the transition to transcritical operation where thermodynamic efficiency is inherently lower (Fig 4). As a result, the suitability of basic CO_2 systems is limited in southern United States or similar climates, where high summer temperatures are common and sustained.

The thermodynamic properties of these HFO blends enable efficient operation without the need for extensive system adaptations or auxiliary components. This stability ensures predictable operational costs, reduces the likelihood of performance-related interruptions, and enhances overall system reliability for end users.

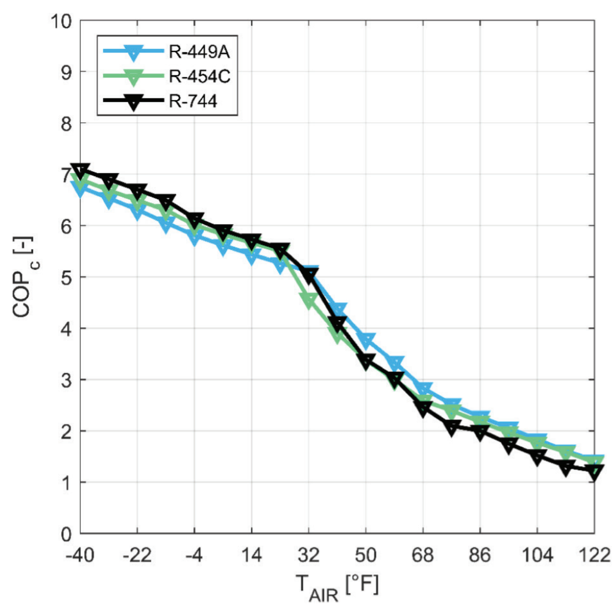


Figure 4: COP vs ambient air temperature

Annual Energy Consumption

Figure 5 compares annual energy consumption for R-454C, R-449A, and R-744 in six U.S. cities across six ASHRAE climate zones. Both R-454C and R-449A demonstrate consistently lower energy use than CO_2 (R-744), with R-449A achieving the lowest values in all locations (Fig 5). The energy savings of HFO blends become more significant in warmer climates, highlighting their advantage for supermarkets in southern and other warmer climate regions.

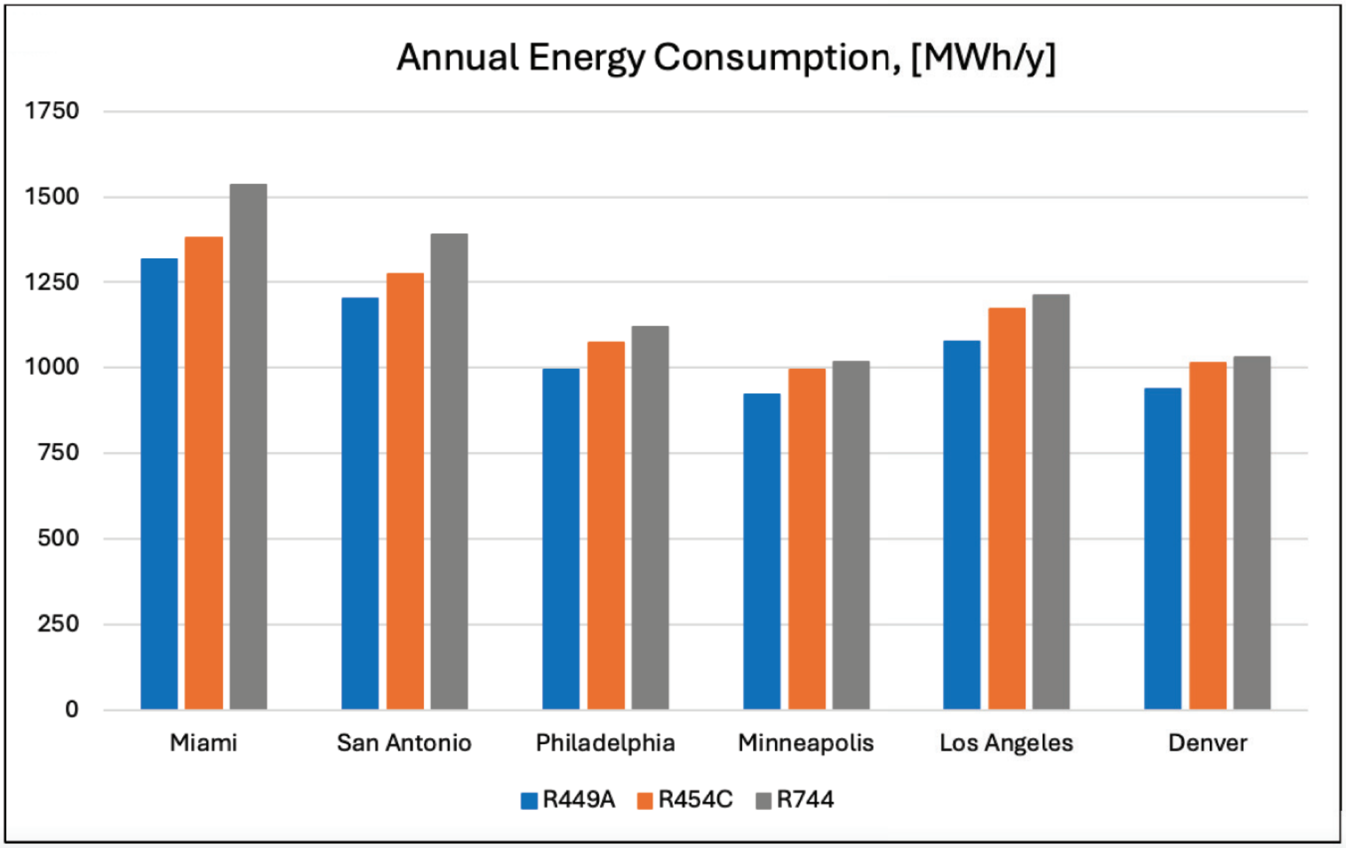


Figure 5: Energy consumption of R-449A, R-454C and R-744 across 6 different climate zones

Seasonal Coefficient of Performance (sCOP)

Seasonal efficiency analysis reveals that R-449A delivers the highest sCOP, followed closely by R-454C, while R-744 exhibits the lowest sCOP across all cities. As ambient temperatures rise from Minneapolis to Miami for example, the performance gap between the HFO blends and R-744 widens, confirming the superior year-round efficiency of R-454C and R-449A (Fig 6).

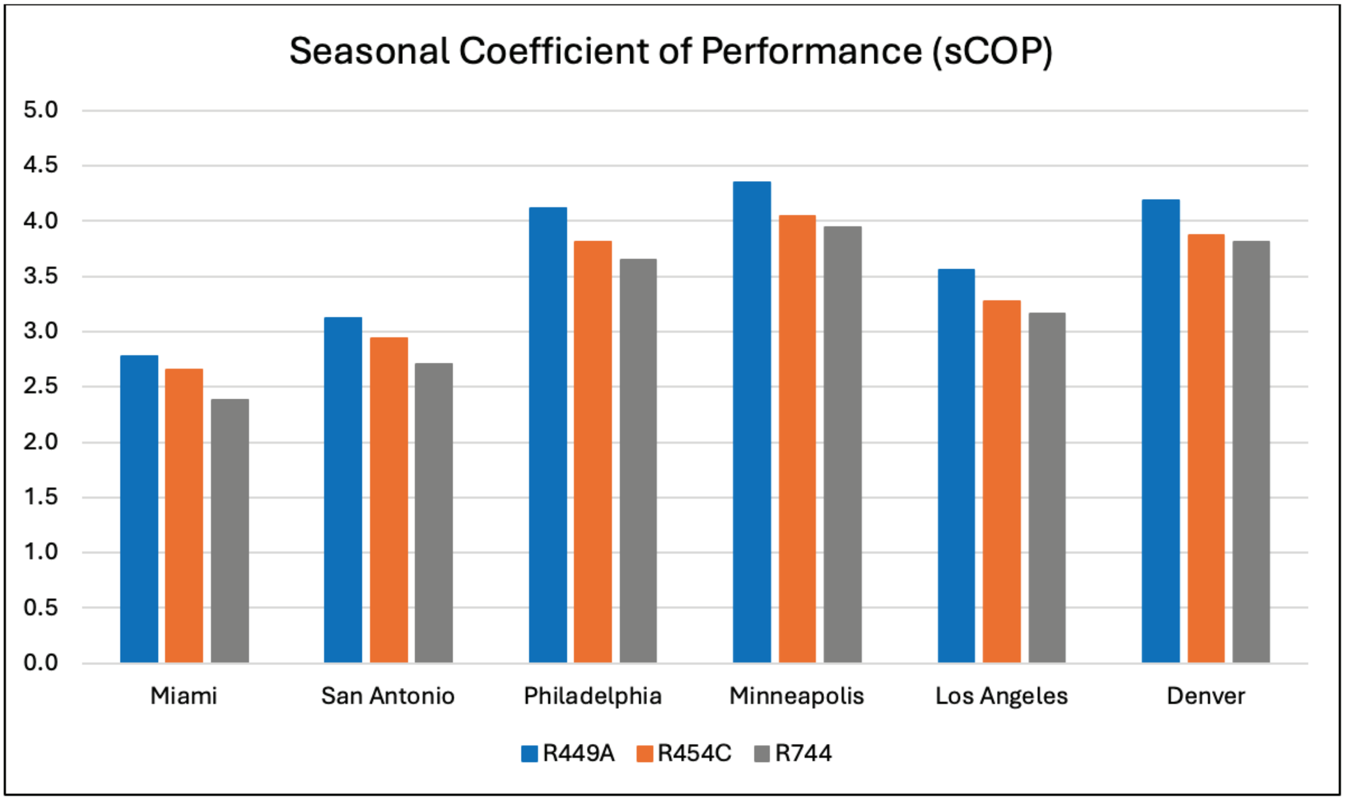


Figure 6: Seasonal Coefficient of Performance (sCOP) of R-449A, R-454C and R-744 across 6 different climate zones

Key Take Aways

In summary, the findings of this study clearly indicate that Opteon™ XL20 (R-454C) and Opteon™ XP40 (R-449A) stand out as optimal refrigerant solutions for both new installations and retrofits (Opteon™ XP40) in supermarket refrigeration, particularly in regions exposed to elevated ambient temperatures. Their superior energy efficiency and compatibility with existing system architectures make them especially attractive for operators and designers seeking to minimize both operational complexity and costs.

From a sustainability and policy perspective, the adoption of low-GWP, high-efficiency refrigerants like Opteon™ XL20 (R-454C) and Opteon™ XP40 (R-449A) are a critical step in accelerating decarbonization across the refrigeration sector. Continued support for the deployment of these advanced refrigerants—alongside further research addressing total environmental impacts, including refrigerant leakage—will help ensure that sustainability targets are met in a comprehensive manner.

Finally, evaluation of capability to use existing and/or conventional infrastructure should also be taken into consideration. Collectively, these considerations underscore the importance of a holistic approach—integrating efficiency, sustainability, and practical system design—for the future of supermarket refrigeration.

This independent study underscores the potential for low-GWP HFO refrigerants—particularly R-454C and R-449A—to drive significant energy and emissions reductions in commercial food retail refrigeration. As the industry transitions toward climate-neutral operations, evidence-based refrigerant selection will be crucial.

For additional information, please contact Tech2Tech Support at 866-433-TECH or tech2tech@chemours.com.

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