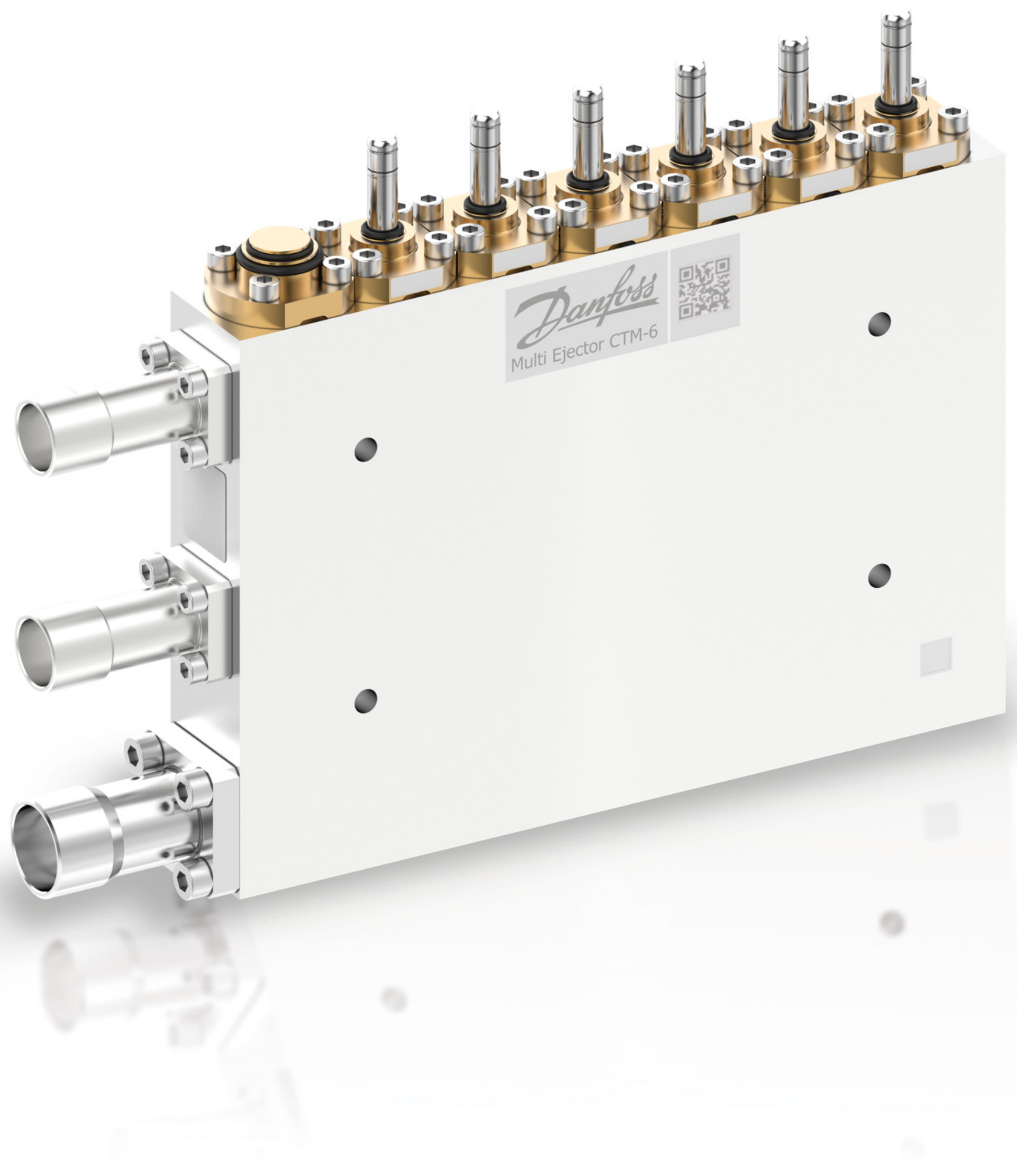
Whitepaper | Multi Ejector HP

By Chris Brown

Danfoss Multi Ejector High Pressure (HP): Unlocking 21% Savings over Traditional CO_2 Booster Systems



Test results show that the Danfoss ejector provided significant energy savings even when ambient temperatures exceeded 35°C (95°F).

It takes special ingredients to lower energy consumption at higher temperatures.

In typical transcritical CO_2 booster systems used in supermarket refrigeration, low-temperature (LT) compressors discharge CO_2 gas to medium-temperature (MT) compressors, which then discharge at high pressure levels to the gas cooler. When refrigerant temperatures are high — above 31°C (87.8°F) — the CO_2 does not condense into a liquid in the gas cooler but is cooled as a supercritical fluid.

There's a considerable amount of energy packed into that fluid, which typically exits the gas cooler at up to 89.6 bar (1300 psi). Despite its potential, that high-side energy is wasted in systems that throttle the fluid through the high-pressure valve back to the receiver, where vapor is then passed back to the MT compressors, resulting in increased run time.

This waste is especially acute in warmer climates. But there is a solution. The flash gas from the receiver can be piped to one or more dedicated intermediate-temperature (IT) compressors, which can then operate at lower pressure ratios and consume less energy (see Figure 1).

And there's a way to save even more energy. Adding a high-pressure lift (HP) ejector into the system utilizes the Venturi Effect to draw a portion of the mass flow of CO_2 from MT evaporators, then return it to the receiver at higher pressure without the need for mechanical compression (Figure 2). Gas drawn by the HP ejector will be absorbed by the IT compressors.

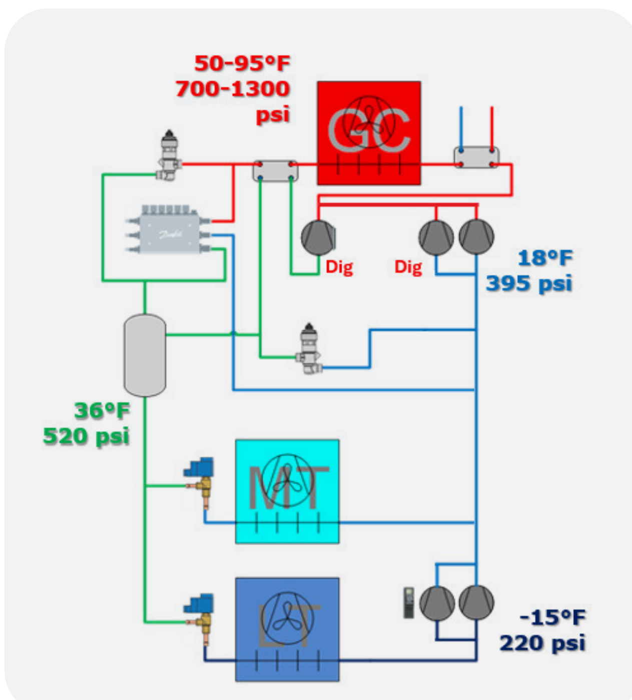


Figure 1 illustrates the transcritical-booster-system design used in Multi Ejector HP testing. The efficiencies gained through the Venturi Effect, parallel compression, and reduced compressor cycling improved system stability and energy efficiency. (AK-PC 782A Pack Controller not shown.) For the base condition, the ejector is shut off electronically and the high-pressure relief valve allows the gas to flow through parallel piping to the receiver bypassing the ejector.

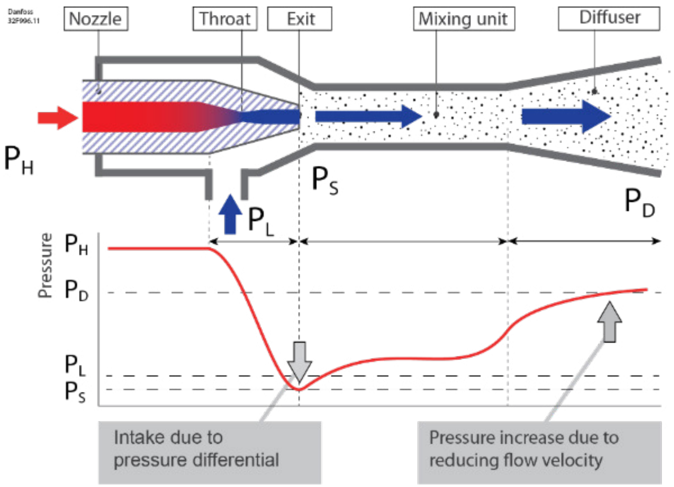


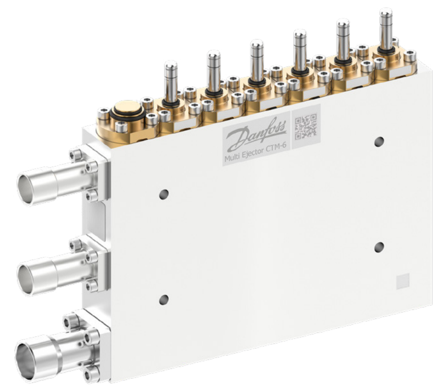
Figure 2 illustrates the Venturi Effect as employed by the Multi Ejector HP. High-pressure CO_2 gas from the gas cooler enters the ejector's high-pressure port (PH) and flows through the throat which causes the flow to accelerate. The gas exits the ejector nozzle at supersonic speed, creating a low pressure (PS) zone, lower than the pressure of CO_2 flowing into the ejector from the suction port (PL). The two flows are mixed in the mixing chamber and finally enter the diffuser at a higher pressure from the discharge port (PD). The kinetic energy of the flow (velocity) performed work for "free," raising pressure from PL to PD without the need for mechanical compression.

This white paper discusses recent field tests of Danfoss Multi Ejector HP factory-installed on Hussmann booster systems in two different U.S. locales — a mild climate in the Midwest and a warmer climate in the South. Test results show that the Danfoss ejector provided significant energy saving even when ambient roof temperatures exceeded 35°C (95°F). Appreciable savings continued as low as 10°C (50°F) ambient, showing that the Multi Ejector HP solution can tap the potential of high-pressure CO_2 to unlock additional energy savings for supermarket booster systems operating in mild to hot climates.

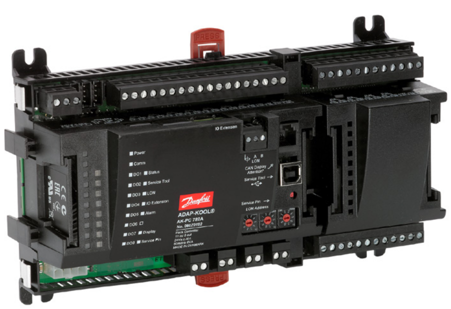
The science of ejectors makes sense and saves dollars.

The energy potential of CO_2 in a transcritical booster system is contained in highly pressurized CO_2 fluid created during the compression cycle and the subsequent rejection of its excess heat. In high-pressure transcritical systems used for supermarket refrigeration, this potential energy can be tapped by employing parallel compression and ejector technologies, which utilizes energy that would be otherwise lost during the fluid's expansion phase and the associated increase in compressor workload.

Parallel compression enables an intermediate (IT) compressor to handle gas from the receiver or flash tank at a higher pressure (e.g., 520 psi), rather than dropping to the lower medium temperature suction level (Figure 1). By operating at this elevated suction pressure, the IT compressor delivers greater capacity with less work, which reduces the heat of compression and lowers overall energy consumption. The effectiveness of a parallel booster system increases with rising ambient temperatures, since a larger share of the refrigerant mass flow going to the receiver is flash gas.



Danfoss Multi Ejector HP type CTM 6 with six replaceable cartridges housed in a compact aluminum block: used in conjunction with the Danfoss AK-PC 782A Pack Controller.



Danfoss AK-PC 782A Pack Controller: controls rack operation, valve logic, and ejector staging in addition to incorporating alarm logic.

Ejectors further enhance the rack's energy savings by harnessing the energy potential of high-pressure CO_2 from the gas cooler, as described in Figures 1&2. It draws mass flow from the medium temperature suction and transfers it directly to the receiver—at no additional cost—before it moves onto the IT compressor. The lower pressure ratio of the IT compressor reduces the rack's power consumption, improving the system's Coefficient of Performance (COP).

Combining parallel compression and an ejector in an integrated system is the special ingredient that not only gets more useful work from carbon dioxide's refrigeration cycle, but the solution also potentially reduces compressor cycling and cumulative current inrush, enhancing the reliability of the supermarket's refrigeration system.

Danfoss Multi Ejector HP results in additional energy savings of up to 13.4%

To measure the energy savings from an ejector compared to parallel compression alone, Danfoss field-tested Multi Ejector HP technology across a range of temperatures at two sites. The Danfoss ejector portfolio includes models for low-pressure booster systems without parallel compression, for high-pressure systems with parallel compression, and liquid models for booster or parallel compression.

In this test case, a six-cartridge Multi Ejector HP type CTM 6 was employed in a Hussmann transcritical booster system using parallel compression, newly installed in a new supermarket. About the size of a laptop computer, the ejector is housed in a compact aluminum block mounted directly on the rack.

The Multi Ejector HP lifts some of the gas from the MT suction to the receiver. After leaving the receiver, the gas is compressed directly by the parallel (IT) compressor. When ejectors are operating, part of the MT load is moved to the parallel (IT) compressor to reduce the load on the MT compressors. As the parallel IT compressors operate at a higher suction pressure, system energy consumption is reduced.
In cold ambient conditions, the HP ejector serves the same functions as a conventional high-pressure valve, controlling the system at the COP optimum.

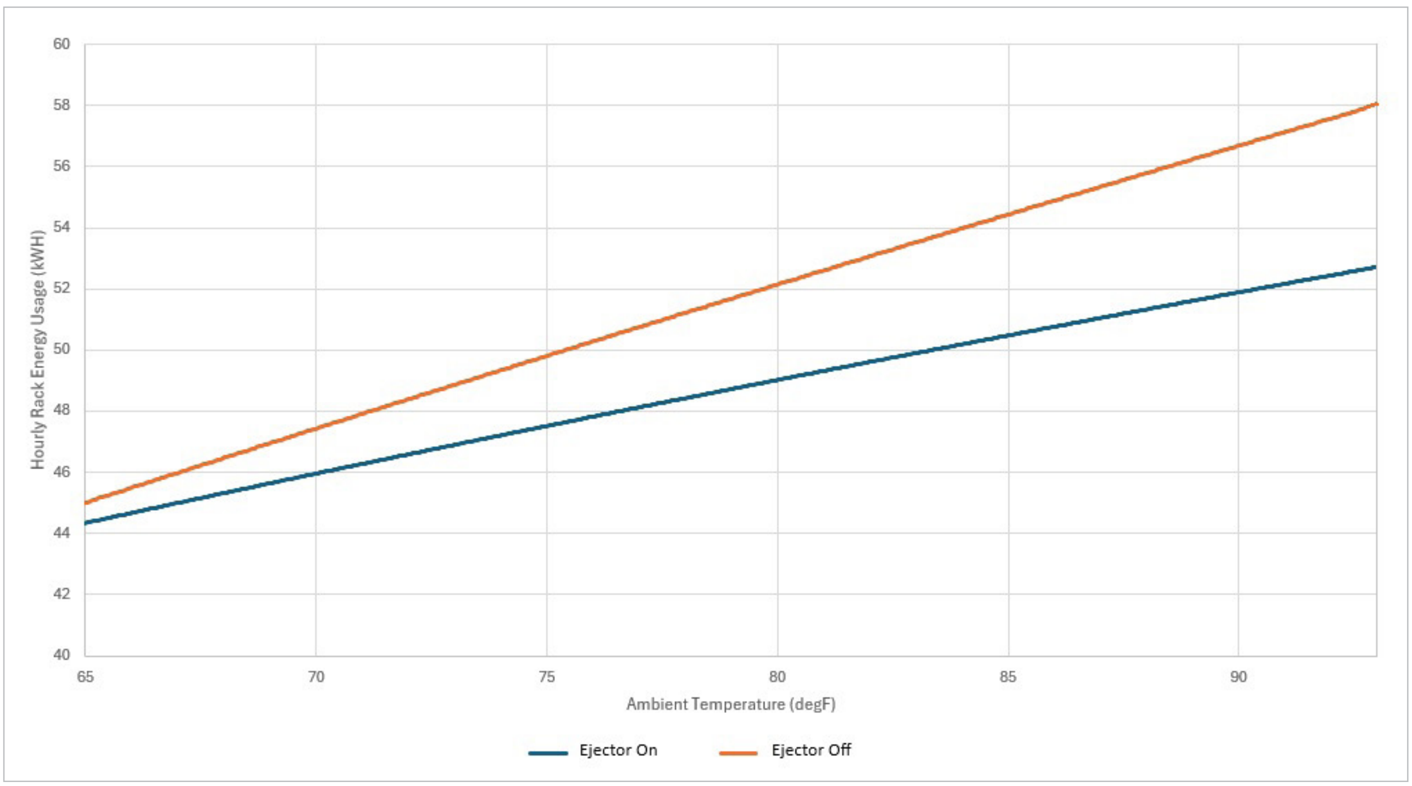
Theoretically, HP ejectors can increase the pressure (also known as *lift*) up to 6 bar (87 psi) at 23°C (73°F) with an entrainment ratio of 25%. The entrainment ratio serves as a performance metric for ejectors, indicating the ejector's ability to recover expansion work that would otherwise be lost through the throttling valve. More specifically, 25% signifies that for every pound (or kilogram) of high-pressure primary flow entering the ejector, 0.25 pounds (or kilograms) of low-pressure secondary (suction) flow is drawn in and compressed without using mechanical compression. At 36°C (97°F), the lift can reach 11 bar (160 psi) at the same entrainment ratio of 25%.

A rack controller — the Danfoss AK-PC 782A Pack Controller — was also used to manage variable pressures in the receiver and to control rack operation, valve logic, and ejector staging, thereby ensuring optimal performance under all conditions.

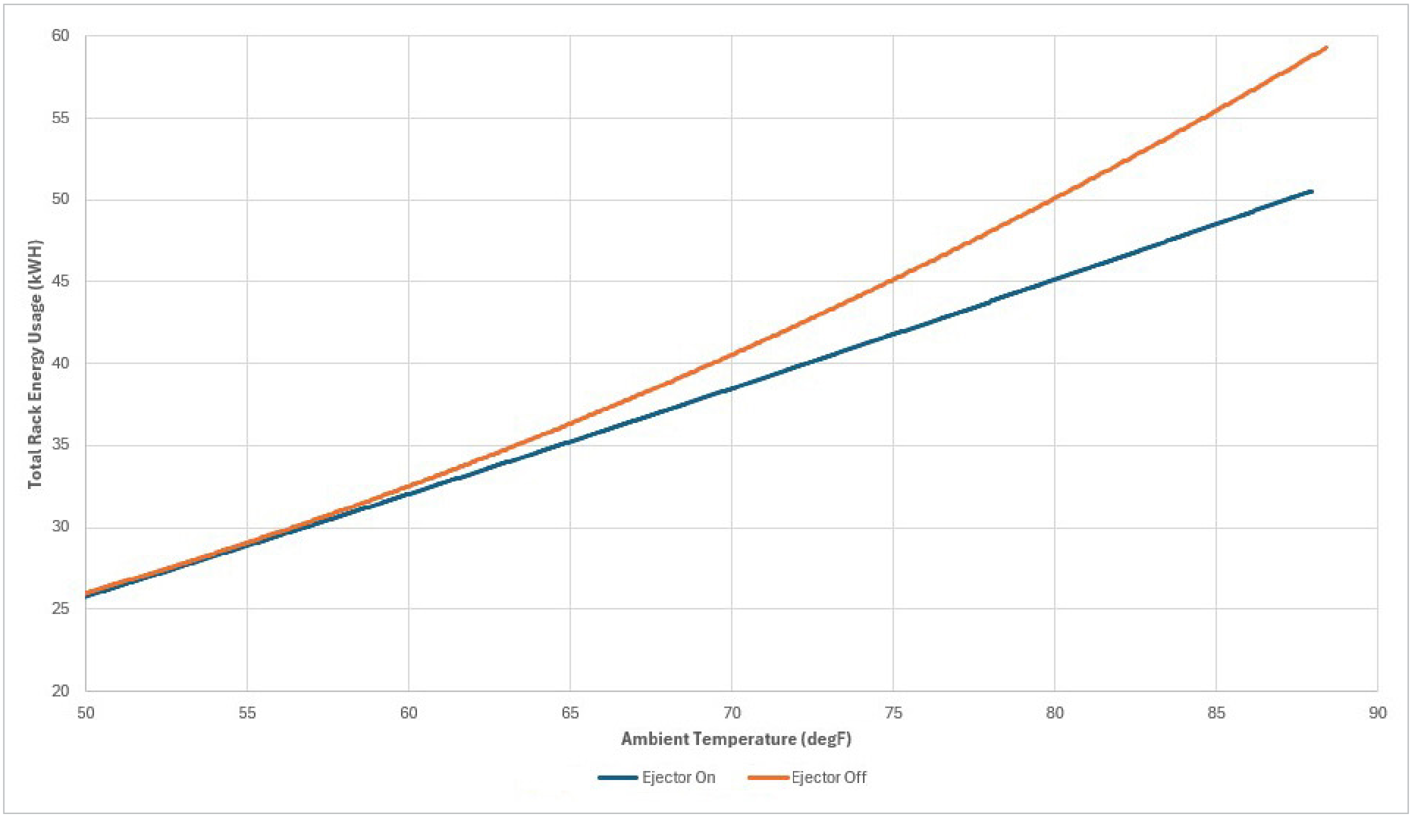
The goal of the project was to test whether any additional savings could be gained by using Multi Ejector HP compared to the expected savings of using parallel compression alone.

The Hussmann system was newly built with parallel compression and an ejector installed. System components (with temperature and pressure ranges and setpoints noted in Figure 1) include:

- Six-cartridge Multi Ejector HP type CTM 6
- Danfoss AK-PC 782A Pack Controller
- Discharge/Gas Cooler (50-95°F, 700 psi-1300 psi)
- Receiver (36°F, 520 psi)
- Redundant High-Pressure Valve to the Receiver
- Flash Gas Bypass Valve
- Suction Accumulator
- Low Temperature (LT) Compressors (-15°F, 220 psi)
- Medium Temperature (MT) Compressors (18°F, 395psi)
- Intermediate (IT) Compressor (36°F, 520 psi)



Site 2 (warmer climate) comparing hourly energy usage with ejector ON vs. OFF



Site 1 (milder climate) comparing hourly energy usage for ejector ON vs. OFF

Test method and results

Method

Tests were conducted in two new stores, one in a mild climate and one in a warmer climate, over several months.

For comparison, the controller electrically switched the ejector ON and OFF. The ejector was piped in permanently, and while electronically disabled for OFF tests, a redundant HP valve controlled the fluid entering the receiver.

Typical pressures for the receiver were regulated to approximately 520 psi. Gas-cooler outlet temperatures and pressures varied with ambient conditions.

Predictions of kilowatt usage and energy savings were made based on theoretical performance values. Measurements of actual kilowatt usage and compressor cycles were taken from controller readouts. Energy meters were placed on each compressor and gas cooler and the data was aggregated from the two sites to determine average energy savings across the ambient temperature range.

Results

With the ejector ON, actual incremental energy savings were obtained of up to ~13.4% with ambient temperatures of ~95°F (Chart 1) over the system running with parallel compression only. Actual savings exceeded pre-test projected savings of ~11% (Chart 2). Savings began to appear at lower temperatures than expected, as low as ~50°F in the gas-cooler-outlet region, then increasing sharply around 65–70°F.

Compressor cycling was also reduced with ~43–47% reduction in on/off cycles with ejector ON. For example, weekly counts dropped from 499 to 263 on the parallel compressor (Chart 3). Reduced cycling was also accompanied by reduced inrush current.

Climate sensitivity was also positive. Warmer conditions increased gas-cooler pressure/velocity, opening more solenoids, thereby amplifying savings. But performance at lower ambient temperatures demonstrated that benefits remained even with cooler temperatures.

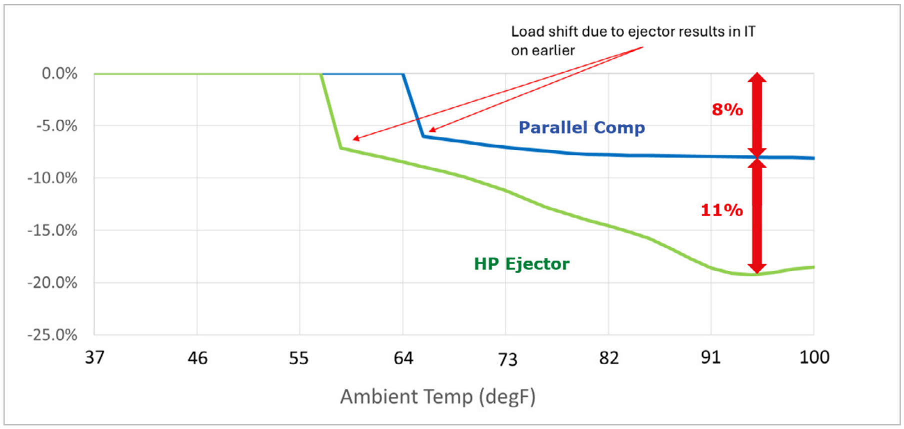


Chart 1:
Projected Energy Savings vs. Standard Booster.

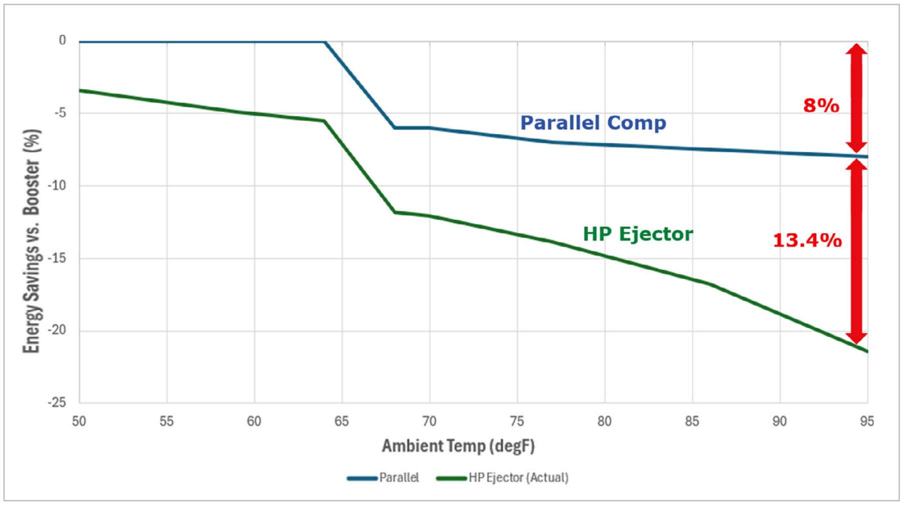


Chart 2:
Actual Energy Savings vs. Standard Booster.

5 Comp. Rack	MT1 Weekly Cycles	MT2 Weekly Cycles	IT Weekly Cycles
Ejector Off	0	482	499
Ejector On	0	273	263
Reduction	--	-43%	-47%

- Average weekly cycle counts taken over a 4-week period
  - 2 weeks ejector on, 2 weeks ejector off

Chart 3:
Weekly Comp Cycle Counts Comparing Ejector On vs Off

Conclusion: Combining higher energy savings with greater rack stability

Conclusion

The field results from this multi-month, multi-climate evaluation demonstrate that integrating a Multi Ejector HP unit into a transcritical booster system with parallel compression provides significant energy savings for supermarket refrigeration. Compared to the same rack operating with the ejector electronically disabled, Multi Ejector HP consistently reduced total energy consumption—achieving savings up to 13.4% at peak ambient conditions. Outperformance was also obtained even at unexpectedly low gas-cooler-outlet temperatures near 50°F.

Moreover, the ejector significantly stabilized rack performance by cutting compressor cycling as much as 47%, reducing cumulative inrush current and mechanical wear. This results in extended equipment life and cost savings.

Taken together, test results indicate that Danfoss Multi Ejector HP technology taps the significant energy potential of transcritical CO_2 to boost energy savings in booster systems with parallel compression in practically any supermarket refrigeration site.

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Danfoss.us
1-888-DANFOSS
E-mail: DanfossNorthAmerica@danfoss.com

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