Trends in Refrigerant System Architecture and CO₂

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Emerson Climate Technologies
What’s Hot in Supermarket Refrigeration

**Energy**
- MT Cases With Doors
- LED Lighting
- Low Condensing
- ECM Fan Motors for Condenser & Case Fans

**Environment**
- EPA Proposal to Delist R404A
- R-22 Retrofits
- Natural Refrigerants
- LCCP Analysis

**Equipment**
- Mechanical to Electronic Control
- Connected Devices/Mobile
- Technician Shortage
- ASHRAE Commissioning Guide

**Economics**
- Information Age (Traceable, Feedback)
- Millennials (E-commerce, Local, Organic)
- “Smaller” Format Stores
- Foodservice Integration
$35k/Year Energy Savings per Store by Implementing Low Condensing

**Boston Temperature Profile**

- Days per Year with Temperatures:
  - 5°F: 20%
  - 25°F: 80%
  - 45°F: 70%
  - 65°F: 90%
  - 85°F: 50%

**Compressor Performance**

- Condensing Temperature vs. Compressor Efficiency:
  - Approximately 20% increase in compressor efficiency for a 10°F drop in condensing temperature.

**Opportunity For Savings**

- 5°F: 90%
- 25°F: 70%
- 45°F: 80%
- 65°F: 90%
- 85°F: 50%

**Total Annual Cost (@ $0.9/kWh)**

- 50 Min Cond: $35K Savings
- 70 Min Cond: $100K
- 90 Min Cond: $150K

**Typical Boston Supermarket**

- 50 Min Cond: 35% Savings
- 70 Min Cond: 14% Savings
- 90 Min Cond:
CoreSense Provides Step Change in System Reliability & Troubleshooting

Compressor Protection & Control
- Discharge Temperature Protection
- Liquid Injection Control via Electronic Stepper Valve
- Digital Modulation Control
- 15 LED Alarm Codes
- Remote Communications (Modbus)
- Phase Monitoring, Short Cycling, Welded Contactor & Proofing Through Current Sensing

Remote Communications & Reset
- Alarm Status
- Discharge Temp
- Run Time/Cycle Count
- Model & Serial #
- Amps
- 7-Day Alarm History

Equipment
Convenience, Fresh, Specialty & E-Commerce Shake up Grocery Landscape

Walmart U.S. accelerates small store growth
Expansion program doubles initial forecast

Walmart Hopes To Boost Sales By Opening Convenience Stores

Target to Open 'Smallest Location Ever'
Test store will feature "everyday essentials," including grab-and-go sandwiches

Dollar General and Family Dollar, the New Small Format Grocery Stores?

US organic food market to grow 14% from 2013-18

Aldi to Boost Its Number of U.S. Stores by 50%

Lidl postpones plan to open U.S. stores to 2018

AmazonFresh groceries arrive in Brooklyn
Energy Usage Will Become Primary Source for CO₂ Emissions

Boston, MA LCCP Analysis

<table>
<thead>
<tr>
<th>Description</th>
<th>Annual Energy</th>
<th>LCCP</th>
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<tbody>
<tr>
<td>CO₂ Booster</td>
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<tr>
<td>50°F Min Cond; EXV</td>
<td>-15.3% / -62.9%</td>
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<tr>
<td>Secondary – 300 GWP</td>
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<tr>
<td>50°F Min Cond; EXV</td>
<td>-17.2% / -63.7%</td>
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<tr>
<td>Cascase – 300 GWP MT</td>
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<tr>
<td>50°F Min Cond; EXV</td>
<td>-12.5% / -61.6%</td>
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<tr>
<td>1500 GWP DX</td>
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<td></td>
</tr>
<tr>
<td>50°F Min Cond; EXV</td>
<td>-14.8% / -44.1%</td>
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</tr>
<tr>
<td>70°F Min Cond; TXV</td>
<td></td>
<td></td>
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<tr>
<td>1500 GWP DX</td>
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<td></td>
</tr>
<tr>
<td>70°F Min Cond; TXV</td>
<td>-3.4% / -39.1%</td>
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<tr>
<td>R404A DX</td>
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- LT = Low Temperature
- MT = Medium Temperature
- DX = Direct Expansion
- LCCP = Life Cycle Climate Performance

E360
Understanding Assumptions Critical for “Apples to Apples” Comparisons

- Minimum Condensing Temperature
- Compressor Superheat
- Subcooling
- Temperature Differential (TD)
Refrigerant Change Being Driven by Regulations & Voluntary Actions

**Regulations**

- Montreal Protocol Targets Ozone Depletion (R-22) Signed 1987
- North American Proposal Targets CO₂ Emissions (High Global Warming)

**Organizations**

- United Nations Framework Convention on Climate Change
- CCAC
- IPCC
- INTERGOVERNMENTAL PANEL ON climate change
- California Environmental Protection Agency
- Air Resources Board
- Danish Ministry of the Environment Environmental Protection Agency
  HFC Ban & Tax
- European Commission
  F-Gas Regulation
- The Consumer Goods Forum
- Green Chill
- U.S. Environmental Protection Agency
  Advanced Refrigeration Partnership
- Shecco
  Natural Refrigerants
Natural Refrigerants Gaining Traction in North American Supermarkets

Leading Edge Field Trials

<table>
<thead>
<tr>
<th>Supermarket</th>
<th>Location</th>
<th>Refrigerant</th>
<th>Type</th>
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</thead>
<tbody>
<tr>
<td>Walgreens</td>
<td>Evanston, IL</td>
<td>R290 Micro-Distributed</td>
<td>Geothermal, CO₂</td>
</tr>
<tr>
<td>Sprouts</td>
<td>Dunwoody, GA</td>
<td>Transcritical CO₂ Booster</td>
<td></td>
</tr>
<tr>
<td>Albertsons</td>
<td>Carpinteria, CA</td>
<td>Ammonia/CO₂ Hybrid</td>
<td></td>
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</tbody>
</table>

CO₂ Installed Base

Source: Shecco "Guide 2012: Natural Refrigerants for Europe"
Source: ATMOsphere America 2014
Source: Hillphoenix "Market progress.."
General Uses for CO₂

- Fire Extinguishers
- Beverage
- Plants
- Solvent
- Modified Atmospheric Packaging
- Refrigeration
Where Does CO₂ (R744) Come From?

- **By-Product of:**
  - Fermentation of Ethanol
  - Combustion of Fossil Fuels
  - Liquefaction of Air
- **Naturally Occurring in Wells**
- **The Atmosphere Comprises Approximately 0.04% CO₂ (370 ppm)**
- **Manufacturing Process:**
  - Filtration, Drying and Purification
    - Results in Different Grades of CO₂ for Different Applications:
      - Industrial Grade, 99.5%
      - Bone Dry, 99.8%
      - Anaerobic, 99.9%
      - **Coleman Grade, 99.99% (Used in Refrigeration)**
      - Research Grade, 99.999%
      - Ultra Pure, 99.9999%
Benefits of Using CO\textsubscript{2} as a Refrigerant

- CO\textsubscript{2} is a natural refrigerant with very low global warming potential
  - ODP = 0, GWP = 1
- Non-Toxic, Non-Flammable
- CO\textsubscript{2} is an inexpensive refrigerant compared with HCFCs and HFCs
- CO\textsubscript{2} has better heat transfer properties compared to conventional HCFCs and HFCs
- More than 50% reduction in HFC refrigerant charge possible (high volumetric cooling capacity)
- CO\textsubscript{2} lines are typically one to two sizes smaller than traditional DX piping systems
- Excellent material compatibility
- System energy performance equivalent or better than traditional HFC systems in cool climates
Basic Considerations When Using CO$_2$ as a Refrigerant

- The critical point is the condition at which the liquid and gas densities are the same. Above this point distinct liquid and gas phases do not exist.
- The triple point is the condition at which solid, liquid and gas coexist.
- The triple point of carbon dioxide is high (60.6 psi) and the critical point is low (87.8 °F) compared to other refrigerants.

Photo, Courtesy “GreenChill”, Introduction to CO$_2$ Refrigeration, Feb.9, 2012
## Basic Properties of R744, R404A and R134a Refrigerants

<table>
<thead>
<tr>
<th>Refrigerant</th>
<th>R744</th>
<th>R404A</th>
<th>R134a</th>
<th>R407A</th>
<th>R407F</th>
</tr>
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<tbody>
<tr>
<td><strong>Temperature at atmospheric pressure</strong></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Temp of dry ice</td>
<td>-109.3 °F (-78.5 °C)</td>
<td>-50.8 °F (-46 °C)</td>
<td>-14.8 °F (-26 °C)</td>
<td>-41.8 °F (-41 °C )</td>
<td>-45.5 °F (-43 °C )</td>
</tr>
<tr>
<td>(Saturation temp.)</td>
<td></td>
<td>(Saturation temp.)</td>
<td>(Saturation temp.)</td>
<td>(Mid-point saturation temp.)</td>
<td>(Mid-point saturation temp.)</td>
</tr>
<tr>
<td><strong>Critical temperature</strong></td>
<td>87.8 °F (31 °C)</td>
<td>161.6 °F (72 °C)</td>
<td>213.8 °F (101 °C)</td>
<td>179.6 °F (82 °C)</td>
<td>181.4 °F (83 °C)</td>
</tr>
<tr>
<td><strong>Critical pressure</strong></td>
<td>1,055 psig (72.8 barg)</td>
<td>503 psig (34.7 barg)</td>
<td>590 psig (40.7 barg)</td>
<td>641 psig (44.2 barg)</td>
<td>674 psig (46.5 barg)</td>
</tr>
<tr>
<td><strong>Triple point pressure</strong></td>
<td>60.6 psig (4.2 barg)</td>
<td>0.44 psig (0.03 bar abs)</td>
<td>0.0734 psig (0.005 bar abs)</td>
<td>0.19 psig (0.013 bar abs)</td>
<td>TBC</td>
</tr>
<tr>
<td><strong>Pressure at a saturated temperature of 20 °C (68 °F)</strong></td>
<td>815 psig (56.2 barg)</td>
<td>144 psig (9.9 barg)</td>
<td>68 psig (4.7 barg)</td>
<td>133 psig (9.2 barg)</td>
<td>139 psig (9.6 barg)</td>
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<tr>
<td><strong>Global warming potential</strong></td>
<td>1</td>
<td>3922</td>
<td>1430</td>
<td>1990</td>
<td>1824</td>
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</table>
Pressure — Enthalpy Diagram for CO₂
Selecting the Best System
Booster vs. Cascade vs. Secondary
CO₂ Secondary System

- The high stage system (HFC, HC or Ammonia) cools the liquid CO₂ in the secondary circuit like a simple chiller system.
  - CO₂ is cooled to 26 °F (275 psig) for the MT load and -13 °F (181 psig) for the LT load.
- The CO₂ is pumped around the load.
- **It is volatile, so unlike a conventional secondary fluid such as glycol it does not remain as a liquid. Instead it partially evaporates.**
- It therefore has a significantly greater cooling capacity than other secondary fluids.
- This reduces the pump power and the temperature difference at the heat exchanger.
Selecting the Best System
Booster vs. Cascade vs. Secondary

SECONDARY

CASCADE

TRANSCRITICAL BOOSTER
Typical Retail Cascade (Hybrid) System

• **High-stage (HFC) System:**
  – provides cooling for the medium-temperature load
  – removes the heat from the condensing CO\(_2\)
in the low stage at the cascade heat exchanger

• **Low-stage (CO\(_2\)) System:**
  – CO\(_2\) condensing temperature is maintained below the critical point
  – CO\(_2\) pressures are similar to R-410A
  – Utilizes CO\(_2\) as a direct expansion refrigerant
  – Uses efficient and quiet CO\(_2\) subcritical compressors
  – CO\(_2\) specific evaporators
  – Electronic expansion valves with EEVs for steady, automatic control of superheat leaving the evaporators
  – All liquid lines must be insulated
Typical Cascade System Operating Pressures

- **Low-Side (Suction)**
  - Typ. Operating Suction: 200–275 psig

- **High-Side (Discharge and Receiver)**
  - Typ. Operating Discharge: 400–500 psig

Low-Side Pressure Relief (Recip.): 350 psig
Low-Side Pressure Relief (Scroll): 475 psig

Normal Operating Suction: 200–275 psig
High Suction: >275 psig
Low Suction: <200 psig

Low Discharge: <400 psig
High Discharge: >500 psig

Normal Operating Discharge: 400–500 psig

Pressure Regulating Relief Valve: 560 psig
Main Pressure Relief Valve: 625 psig

CO2 Low-Side Suction (psig)
CO2 High-Side Discharge, Separator (psig)

Courtesy of “The Green Chill Partnership and Hill Refrigeration”
Differences in Pressure Between Secondary and Cascade

LT2 — Pumped CO₂ Secondary
225 psig

LTX2 — CO₂ DX Cascade
400–500 psig Discharge
Selecting the Best System
Booster vs. Cascade vs. Secondary

SECONDARY

CASCADE

TRANSCRITICAL BOOSTER
CO₂ Booster Refrigeration System in Transcritical Operation

- CO₂ is circulated in LT and MT sections
- Gas cooler in supercritical mode
- Condenser in subcritical mode
- Three separate sources of suction gas for MT compressors
- LT requires two stages to keep compression ratios low & keep discharge temperatures from exceeding the oil’s temp limit
**CO₂ Booster Refrigeration System**

Transcritical Compressors

- Higher gas density of CO₂ results in smaller compressor displacement with equivalent R404A motor size
- PRV Relief Valves: 66/135 bar (957/1,958 psig) for low/high side
- Max. Operating Pressure = 120 bar (1,740 psig)
- Inverter Release 25–70hz
- CoreSense Protection
• Helps maintain sub-cooling in condenser when in subcritical mode
• Create pressure drop into the flash tank
• Optimizes COP during transcritical operation
High-Pressure Control Examples With Same Evaporator Conditions

• In transcritical operation, lower discharge pressure does NOT always yield higher efficiency

• High-pressure controller optimizes efficiency based on gas cooler outlet temperature

COP = \frac{\text{Heat Energy Removed (BTU)}}{\text{Power Input}}

• In some cases, higher cooling capacity may take precedent over higher COP

• When the ambient drops and system works in Subcritical Mode, lower condensing pressure provide the greatest efficiencies once again
CO₂ Booster Refrigeration System

Bypass Valve

- Bypass valve controls pressure in the receiver / flash tank at a constant level
- Gas is bypassed to the interstage / suction of the MT compressors to help de-superheat
Improving Efficiency With Adiabatic Condensers / Gas Coolers

Allows subcritical operation for as long as possible as ambient starts to rise
CO₂ Booster Refrigeration System
With Parallel Compression

- Flash gas is compressed by a different compressor
- 8% higher efficiency
- Smaller gas cooler
- By-pass valve remains to manage low load and low condensing conditions
CO₂ Booster Refrigeration System

Case Controls and EEV Cases

- Case controls and EEV (PWM or stepper)
- Due to high heat transfer coefficient of CO₂ vs. HFC, if the same HFC rated evaporators are used, greater capacities and lower TD would result with improved efficiency
- Smaller tubing coils can be used to reduce material cost and footprint
CO₂ Booster Refrigeration System

Subcritical Compressors

- LT subcritical compressors are same as those used in cascade systems
- Discharges into suction of transcritical

- High side: 43 bar / 630 psig
- Low side: 28 bar / 406 psig
- Low side “PRV” supplied with (34.4 barg) 500 psig
- Oil: RL68HB POE
CO$_2$ Booster Refrigeration System
Emerson’s Connected Offering

**Emerson Offering**
- Centralized Controller
- Distributed Controller
- Transcritical Compressors
- Subcritical Compressors, Semi & Scroll
- Oil Level Controls
- Compressor VFD
- Condenser Motor VFD
- High-Pressure Controller
- Bypass Valve Controller
- High-Pressure Valves
- Case Controllers
- Electronic Expansion Valves
- System Protectors
- Pressure Transducers
- Leak Detection

Diagram showing the connections and components of the CO$_2$ Booster Refrigeration System.
Conclusions

Transcritical systems are usually used in areas where the ambient temperature is generally low (i.e., predominantly below 68 °F to 77 °F), such as northern Europe, Canada and the northern U.S. New system designs and technology are allowing improved efficiency in warmer climates.

Cascade and secondary systems (subcritical CO₂) are usually used in high ambient areas such as southern Europe, the mid to southern U.S., and much of central and south America, Asia, Africa and Australia.

The use of transcritical systems in high ambients generally results in low efficiency; hence, cascade or secondary systems are preferred in these areas.
1. Introduction
2. CO₂ Basics and Considerations as a Refrigerant
3. Introduction to R744 Systems
4. R744 System Design
5. R744 Systems — Installation, Commissioning and Service
# System Architectures — Multiple Choices Being Evaluated

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<tr>
<th>Architecture</th>
<th>Energy</th>
<th>Environment</th>
<th>Equipment</th>
<th>Economics</th>
<th>Future</th>
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<tbody>
<tr>
<td>Centralized DX</td>
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<td>⚫️</td>
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<td>407→HFO Blend</td>
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<td>Distributed DX</td>
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<tr>
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<td>Hydrocarbons HFOs</td>
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Thank You!

Questions?

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