High Efficiency Low Emission Refrigeration System

2016 Building Technologies Office Peer Review

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

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Project Summary

Timeline:

Start date: 1 October 2011

Planned end date: 30 September 2017

Key Milestones

1. Evaluate lab-scale prototype, 9/30/15
2. Initiate field evaluation of full-scale system, 3/31/16

Budget:

Total Project $ to Date:

- DOE: $1,242k
- Cost Share: *

Total Project $:

- DOE: $1,900k
- Cost Share: *

* In-kind contribution from CRADA partner exceeds DOE funding level; exact total is confidential information.

Key Partners:

Hillphoenix

Danfoss

Luvata

SWEP

Project Outcome:

Develop a supermarket refrigeration system that reduces greenhouse gas emissions by 75% and has 25% lower energy consumption.

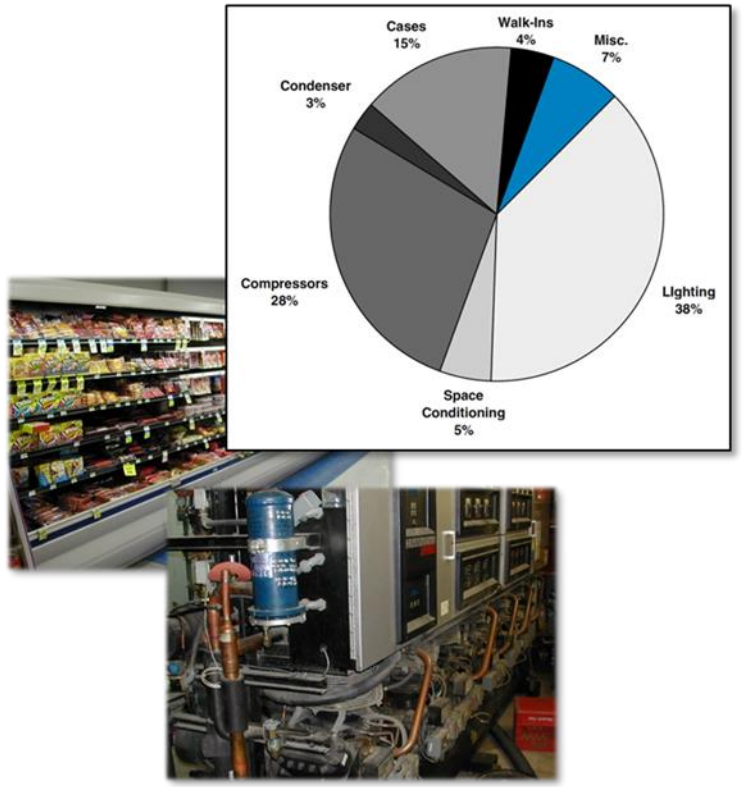
Purpose and Objectives

Problem Statement:

- Develop supermarket refrigeration system:
  - Reduce greenhouse gas emissions by 75%
  - Reduce energy consumption by 25%
- Fabricate prototype systems for:
  - Laboratory evaluation
  - Field evaluation

Target Market and Audience:

- 37,000 supermarkets in the U.S.
- 0.68 quads primary energy consumption for supermarket refrigeration
- Large refrigerant charge per store
  - 2000 to 6000 lb
  - High refrigerant leak rates (up to 25% per year)



Potential Savings:

Emissions: 50 $MMtCO_{2eq}$/yr

Energy: 0.17 quad/yr

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Purpose and Objectives

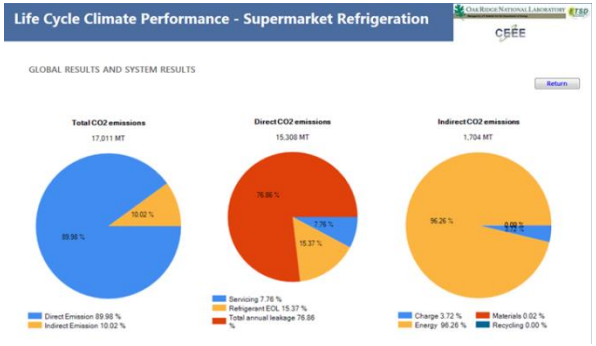
Impact of Project:

- Goal:
  - Develop low emission, high efficiency supermarket refrigeration system:
    - 25% energy savings, 75% emissions reduction
  - Demonstrate system performance:
    - In controlled laboratory setting
    - In third-party installation
- Impact:
  - Encourage implementation of new refrigeration technology:
    - Low emission, high efficiency systems in use in Europe and Canada
    - Encourage market penetration in the U.S.
- Impact Paths:
  - Near term:
    - Product launch by CRADA partner
    - Disseminate system performance data
  - Intermediate/long term: Determine number of systems installed
    - Feedback from owners/operators
    - Proven in-field performance

Approach

Approach:

- Analyze refrigeration system strategies:
  - System types (multiplex DX, secondary loop, CO_2), advanced display case designs, lower Global Warming Potential (GWP) refrigerant options
  - EnergyPlus - evaluate energy consumption
  - Life Cycle Climate Performance (LCCP) modeling - evaluate emissions
- Select prototype refrigeration system:
  - Environmental impact, energy efficiency, cost-effectiveness, marketability, safety and reliability
  - Develop detailed design of prototype refrigeration system



Approach

Approach:

- Fabricate laboratory-scale prototype refrigeration system:
  - Characterize performance under controlled conditions
- Conduct field characterization of the prototype refrigeration system:
  - Install full-scale refrigeration system in a third-party installation
  - Produce field characterization report:
    - Performance of the full scale refrigeration system operating under actual field conditions
    - Insights regarding installation, operation, maintenance, cost

Approach

Key Issues:

- Common multiplex direct expansion (DX) system:
  - Prone to refrigerant leaks:
    - Long piping lengths, high GWP refrigerants
    - High direct emissions
  - Significant energy consumption:
    - High indirect emissions
- Need system with reduced emissions and greater energy efficiency:
  - Lower direct and indirect emissions
  - Cost-effective, safe and reliable

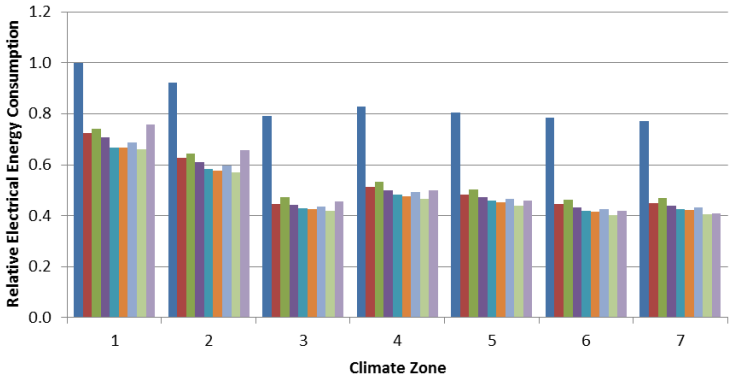
Distinctive Characteristics:

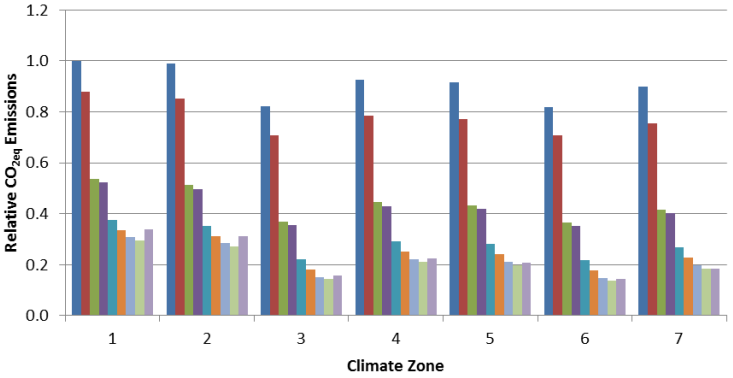
- Refrigeration system developed with industry partner
- System performance characterizations performed:
  - In lab, under controlled conditions
  - In field, under actual conditions

Progress and Accomplishments

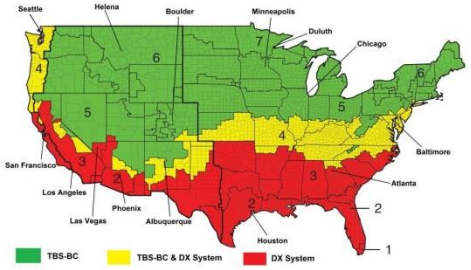
Accomplishments:

- Analyzed energy consumption and environmental effects of various supermarket refrigeration systems
  - Multiplex DX, cascade/secondary, CO_2 transcritical, standard and high efficiency display cases
  - Evaluated energy consumption and LCCP of systems
  - Transcritical CO_2 system: 39% more efficient and 78% less emissions than baseline





R404A Multiplex DX, Std Eff
R404A Multiplex DX, Hi Eff
R404A/CO2 Cascade, PG Secondary, Hi Eff
R404A/CO2 Cascade, CO2 Secondary, Hi Eff
R134a/CO2 Cascade, CO2 Secondary, Hi Eff
R32/CO2 Cascade, CO2 Secondary, Hi Eff
R1234yf/CO2 Cascade, CO2 Secondary, Hi Eff
R717/CO2 Cascade, CO2 Secondary, Hi Eff
Transcritical CO2 Booster, Hi Eff



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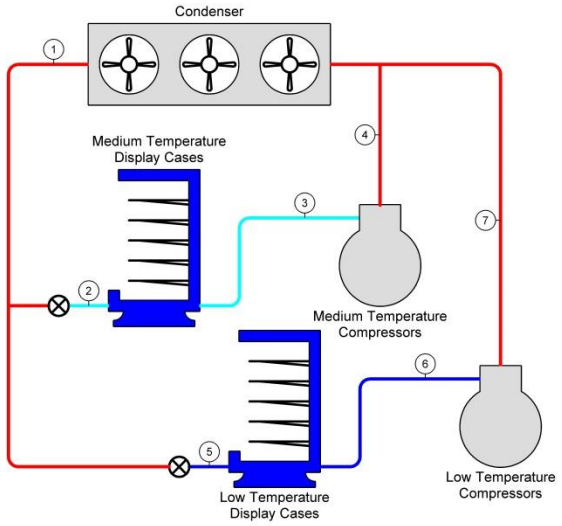
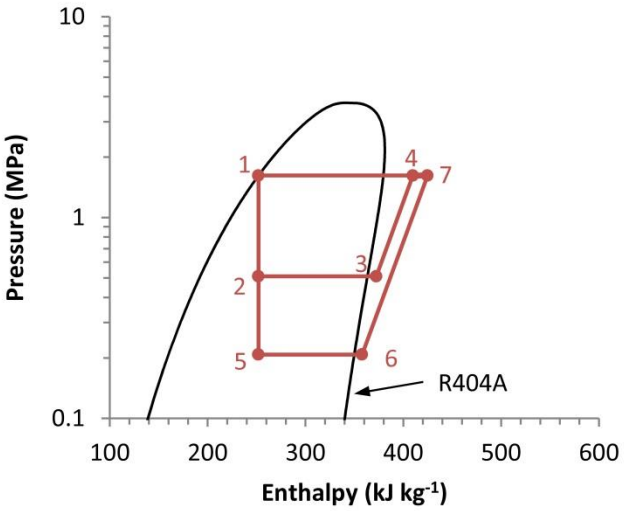
Progress and Accomplishments

Multiplex Direct Expansion (DX) System

Refrigerant: HFC

GWP: High (1600-4000)



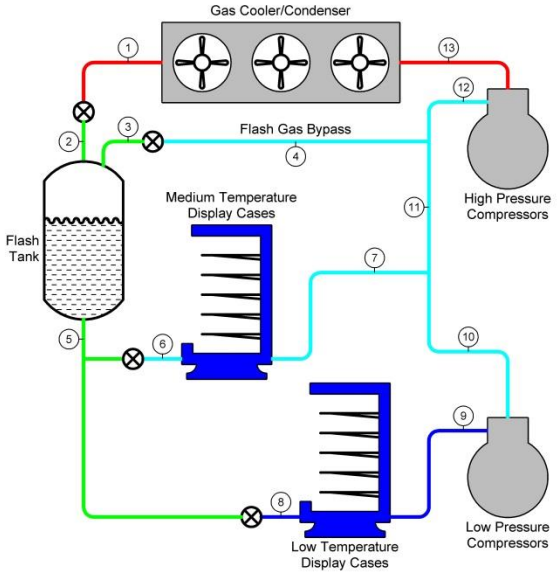


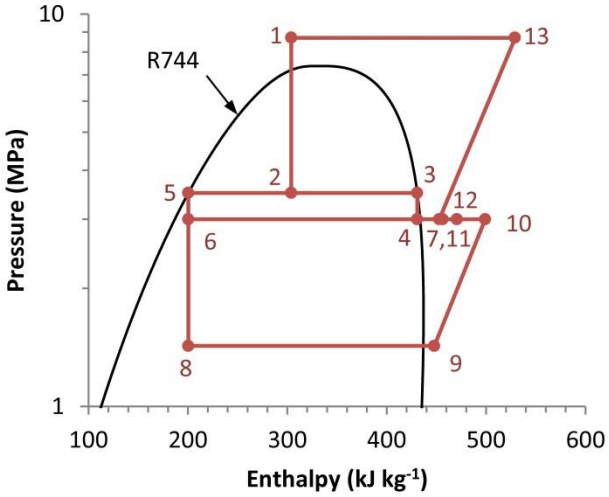
Transcritical CO_2 Booster System

Refrigerant: CO_2

GWP: Low (1)

In use in Europe and Canada, but not in US





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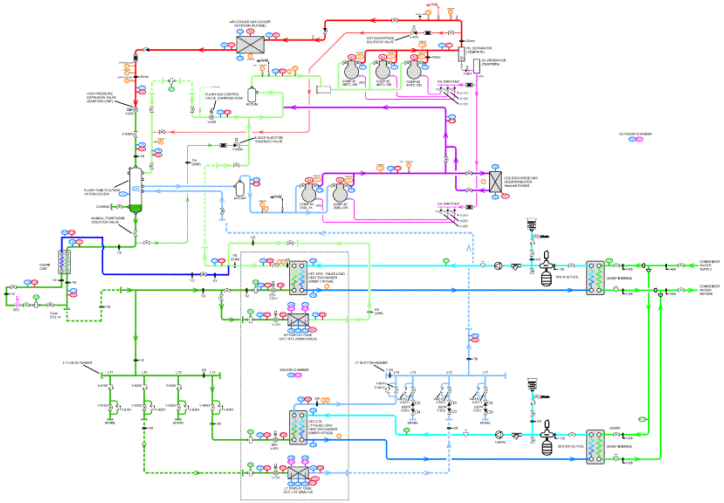
Progress and Accomplishments

Accomplishments:

- Developed prototype system
  - CO_2 transcritical booster
  - Based on results of energy and environmental analysis
  - Prepared design documents

- Fabricated prototype refrigeration system
  - Compressor rack
  - Gas cooler/condenser
  - One MT display case
  - One LT display case
  - MT and LT false loads
  - Fully instrumented
  - Installed in ORNL's environmental chambers

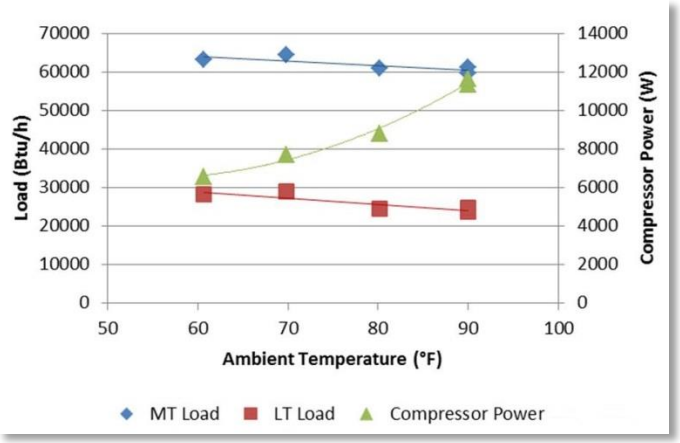


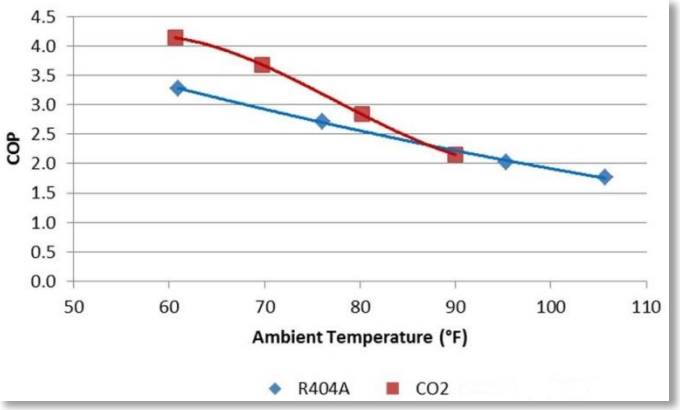
Progress and Accomplishments

Accomplishments:

- Laboratory evaluation
  - Performance determined over temperature range of 60°F to 90°F
  - LT Load: 26,000 Btu/h
  - MT Load: 62,000 Btu/h
  - Compressor power ranged from 6,500 W to 11,500 W
  - COP ranged from 4.1 to 2.1
  - 15% more efficient on average than R404A system over 60°F to 90°F

- Field evaluation
  - Field test site identified
  - Finalizing field evaluation plan, instrumentation requirements, installation logistics





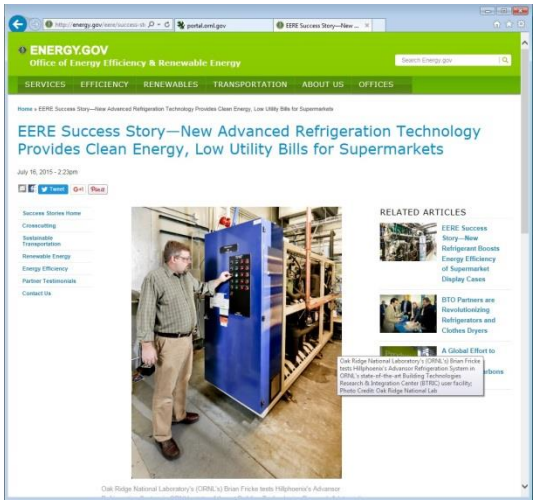
Progress and Accomplishments

Market Impact:

- CRADA partner has commercialized the low emission high efficiency transcritical CO_2 booster refrigeration system
  - Over 130 installations in the US
- Presentations and publications are raising interest in low emission CO_2 refrigeration systems
  - End-users very interested in laboratory and field test results

Awards/Recognition:

- 2015 R&D 100 Award Finalist
- EERE Success Story: New Advanced Refrigeration Technology Provides Clean Energy, Low Utility Bills for Supermarkets
  - http://energy.gov/eere/success-stories/articles/new-advanced-refrigeration-technology-provides-clean-energy-low



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Project Integration and Collaboration

Project Integration:

- Developed refrigeration system in collaboration with industry partners: Hillphoenix, Danfoss, Luvata, and SWEP
  - Collaborate via conference calls, email, site visits, and meetings at conferences
- Professional organizations (ASHRAE, IIR, AHRI, FMI)
  - Interact with equipment manufacturers and end users at conferences

Project Integration and Collaboration

Partners, Subcontractors, and Collaborators:

- ORNL
  - Expertise in HVAC&R equipment performance evaluation and modeling
- Hillphoenix
  - Supplier of commercial refrigeration systems and refrigerated display cases
- Danfoss
  - Supplier of refrigeration systems, sensors, and controls
- Luvata
  - Supplier of heat exchangers, condensers, and gas coolers
- SWEP
  - Supplier of brazed plate heat exchangers

Project Integration and Collaboration

Communications:

Journal Articles

- International Journal of Refrigeration, 46:86-99 (2014) (1 article)

Conference Papers

- ASHRAE Conference, 22-26 June 2013, Denver, CO. (1 paper)
- ASHRAE Conference, 18-22 January 2014, New York, NY. (1 paper)
- 11th International Energy Agency Heat Pump Conference, 12-16 May 2014, Montreal, Canada. (1 paper)
- 15th International Refrigeration and Air Conditioning Conference, 14-17 July 2014, West Lafayette, IN. (1 paper)
- 11th IIR Gustav Lorentzen Conference on Natural Refrigerants, 31 August – 2 September 2014, Hangzhou, China (3 papers, highlighted on R744.com webpage)
- 6th International Institute of Refrigeration (IIR) Conference on Ammonia and CO_2 Refrigeration Technologies, 16-18 April 2015, Ohrid, Macedonia. (1 paper)

White House Factsheets

- https://www.whitehouse.gov/the-press-office/2015/10/15/fact-sheet-obama-administration-and-private-sector-leaders-announce
- https://www.whitehouse.gov/the-press-office/2014/09/16/fact-sheet-obama-administration-partners-private-sector-new-commitments-

Next Steps and Future Plans

Next Steps and Future Plans:

- Complete performance evaluation of transcritical CO_2 refrigeration system in third-party installation

- Develop next-generation transcritical CO_2 refrigeration system for enhanced performance in hot climates
  - Ejectors
  - Parallel compression
  - Mechanical subcooling
  - Adiabatic gas cooling

REFERENCE SLIDES

Project Budget

Project Budget: DOE total $1,900k FY12-17
Cost to Date: $1,242k
Additional Funding: None expected.

Budget History					
10/1/11 – FY 2015 (past)		FY 2016 (current)		FY 2017 – 9/30/17 (planned)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$1,082k	*	$520k	*	$300k	*

* In-kind contribution from CRADA partner – exceeds DOE funding level; exact total is confidential information.

Project Plan and Schedule