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June 16 & 17, 2016 – Chicago

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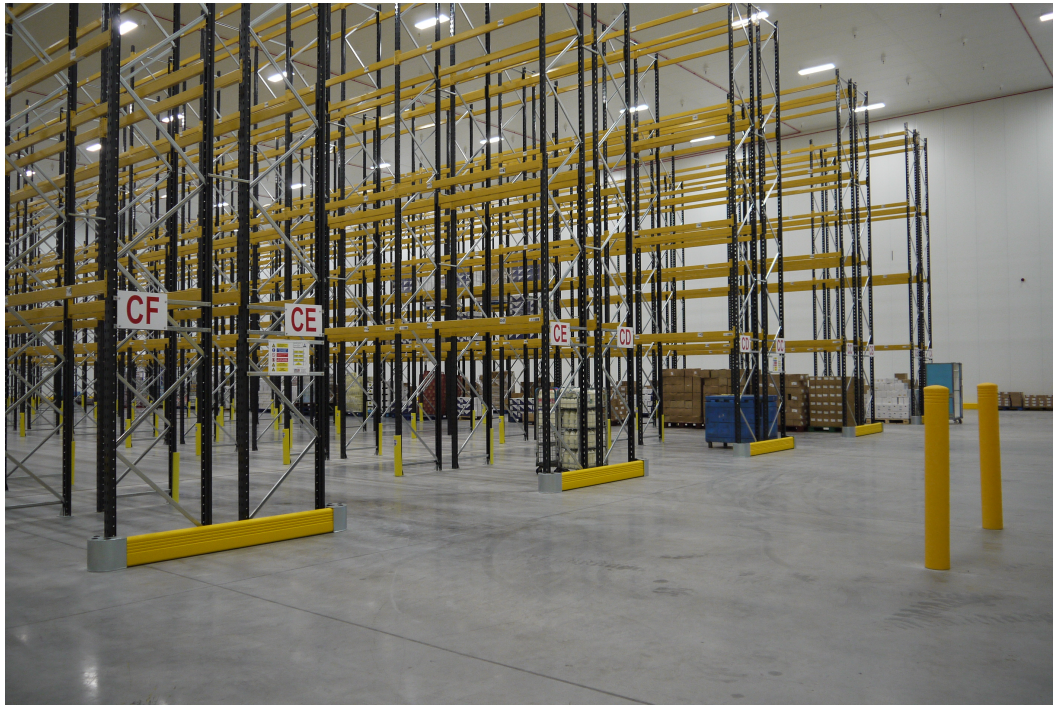
Industrial Refrigeration – Transcritical CO_2

Fresh & Frozen Warehouse

Daniel Clark



Hamilton-Clark Overview

- Independent Refrigeration consultancy since 2004
- Food Retail, Industrial and Pharmaceutical
- Refrigeration Engineers – Specialized in CO_2
  - Technology Strategy Guidance
  - Tailored Specifications & Design
  - Cost Management
  - Choosing Partners & Appraisal
  - Repeatability and Quality
  - Project Management
- First attended CO_2 training in 2005 at the Danish Technology Institute

Why we specialized in CO_2 refrigeration Technology

- Safe – A1 classification.
- Technically an excellent refrigerant.
- Inherent energy efficiency.
- Highly sustainable.
- Dry Expansion (DX) format = transferable maintenance skills from HFC solutions.
- Ensuring that our clients were well ahead of regulatory changes.

Leading our Clients to the right refrigeration solutions

Case Study – Fresh & Frozen Warehouse Transcritical CO_2

Project Details

- Location - Liverpool UK
- 47,000 sq ft & 1.6 M cu ft
- Two Dual Temperature CO_2 Booster Racks
- High redundancy ratio
- Frozen Duty 450,000 BTU/hr or 130 kW
- Fresh Duty 800,000 BTU/hr or 235 kW

Technologies

- Green & Cool / Dorin - Transcritical Booster Systems
- Stepper Expansion Valves – Precise liquid Injection
- High Pressure Pipe work System 870 psi & 1740 psi
- Comprehensive Control System & Internet Connectivity
  - Includes Fire Sprinkler Trace Heating System.
- Electronically Commutated (EC) Evaporator and Gas Cooler Fans
- LED Lighting Throughout

Advantages

- Game Changing Energy Efficiency
- Global Warming Impact vastly reduced from HFC - TEWI
- Low Capital Costs
- None Toxic & None Flammable
- Less Operating Regulations
- Small Bore Brazed Copper Pipe Work
- Light Weight Services
- DX maintenance skills

Energy Benefits

-18% Energy consumption

- Transcritical Technology
- Direct – No Heat Exchange
- Excellent Refrigerant
- Close Control
- LED Lighting

Capital Costs

-28% compared to Ammonia Option

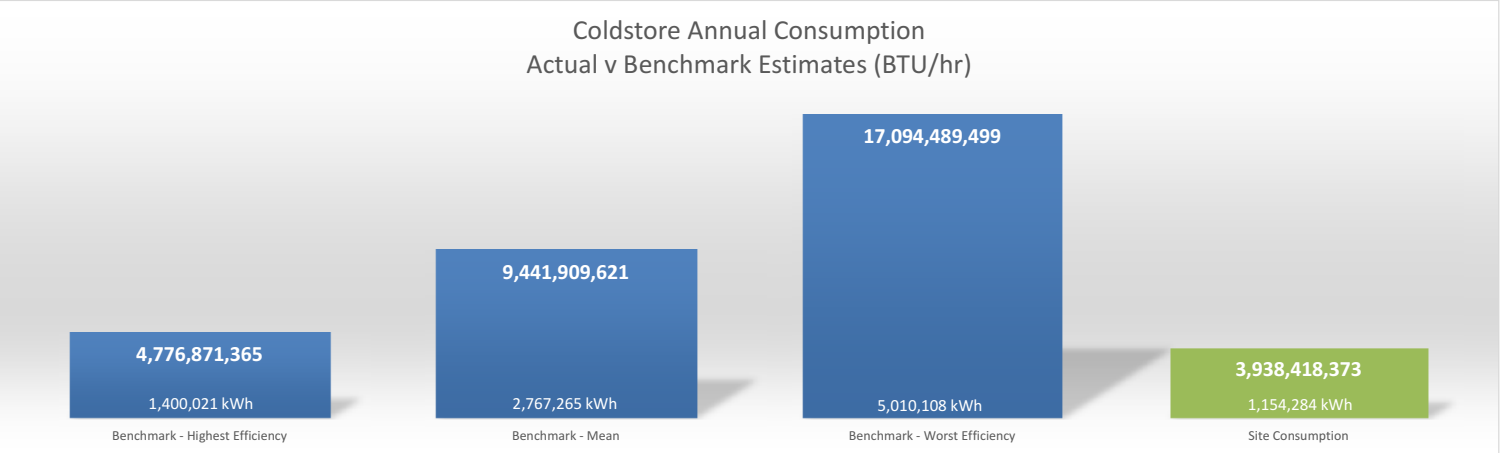
Coldstore Energy Analysis

Hamilton-Clark REFRIGERATION DESIGN & MANAGEMENT

Energy Benchmarks

Benchmarks are taken from ICE-E project ('Improving Cold storage Equipment in Europe') - Study based on 295 coldstore installation datasets (70% EU Countries).

	Site Actual Consumption	Benchmark - Highest Efficiency	Benchmark - Mean	Benchmark - Worst Efficiency
Annual Cost	£103,886	£126,002	£249,054	£450,910
Annual Savings Against Benchmarks	-	£22,116	£145,168	£347,024
% Saving	-	17.55%	58.29%	76.96%

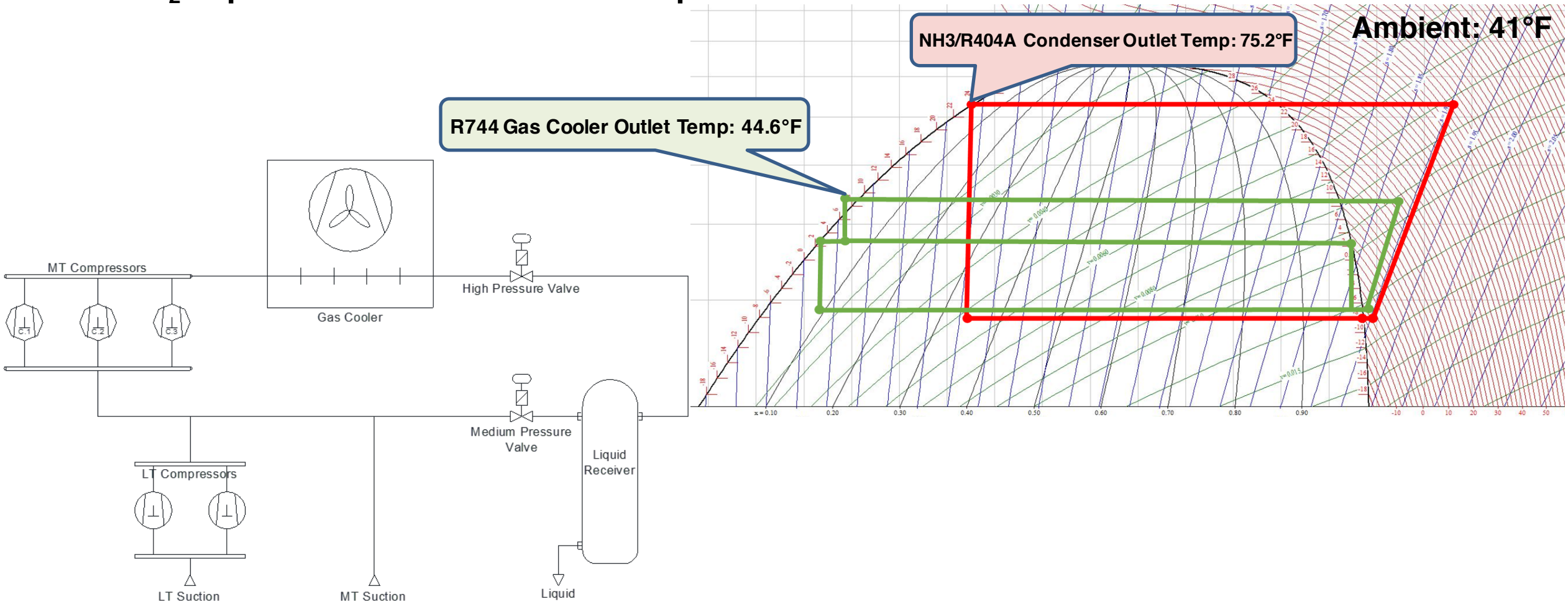


Benchmarks SEC values (Specific Energy Consumption): Mixed Use (Chilled & Frozen). 10% upper & 10% lower values removed. (Page 12, Table 2).

Site figure Includes associated Lighting, Tyco Sprinkler System.

Site Coldstore Area/Volume Total: 46,258.87 ft^2 1,653,554 ft^3

How CO_2 capitalizes on low ambient temperatures



Transcritical CO_2 Energy in relation to ambient temperature

		Normal Daily Mean Temperature (°F)												
State	City	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Year Average
Florida	**Miami**	68.1	69.1	72.4	75.7	79.6	82.4	83.7	83.6	82.4	78.8	74.4	69.9	76.7
Arizona	**Phoenix**	54.2	58.2	62.7	70.2	79.1	88.6	92.8	91.4	86	74.6	61.6	54.3	72.8
Louisiana	**Baton Rouge**	50.1	53.5	60.3	66.6	74	79.7	81.7	81.4	77.5	68.1	59	52.4	67.0
California	**Sacramento**	46.3	51.2	54.5	58.9	65.5	71.5	75.4	74.8	71.7	64.4	53.3	45.8	61.1
North Carolina	**Raleigh**	39.7	43	50.7	59.1	67	74.7	78.8	77.2	71.2	60	51	43	59.6
New Mexico	**Albuquerque**	35.7	41.4	48.1	55.6	64.7	74.8	78.5	76.1	69.1	57.3	44.4	36.1	56.8
New York	**New York**	32.1	34.6	42.5	52.5	62.6	71.2	76.5	75.1	67.5	56.6	47.1	37.3	54.6
Kansas	**Topeka**	27.2	33.4	44.2	54.5	64.4	73.9	78.4	76.7	68.1	56.6	42.6	31.4	54.3
Colorado	**Denver**	29.2	33.2	39.6	47.6	57.2	67.6	73.4	71.7	62.4	51	37.5	30.3	50.1
Washington	**Olympia**	38.1	40.5	43.6	47.4	53.3	58.2	62.8	63.3	58.3	49.7	42.4	38	49.6
Minnesota	**Minneapolis**	13.1	20.1	32.1	46.6	59.3	68.4	73.2	70.6	61	48.7	32.5	18.7	45.4
Montana	**Helena**	20.2	26.4	35.1	44.1	52.9	61.2	67.8	66.7	56.1	44.8	30.9	21.4	44.0
Maine	**Caribou**	9.5	13	24.6	38.1	51.6	60.8	65.6	63.4	53.8	42.8	30.6	16.4	39.2

Simplified performance assessment

Up to 50% more efficient in low ambient temperatures

Consider time at temperature

Ambient (°F)	R744	R404A	NH3-Glycol
33.8	7.59	4.02	3.93
41	7.02	4.02	3.93
50	5.43	4.02	3.93
59	4.31	4.02	3.93
68	3.29	3.76	3.76
77	2.51	3.26	3.35
86	2.05	2.74	3.06
95	1.6	2.38	2.80

Operating Conditions:
COPs based on an MT load of 102,364 BTU/hr.

CO2 & R404A evaporating temp of 17.6°F with 10K Superheat (5k Useful).
NH3 evaporating temp of 10.4°F with 1K Superheat.

CO2 Gas Cooler outlet temp of Ambient +2K & a sub-critical condensing temp of Ambient +5K (47.8°F Min)
R404A & NH3 condensing temp Ambient +6K (75.2°F Min).

Transcritical CO_2 and the Industrial Future

- CO_2 is already used as a pumped secondary refrigerant in industrial refrigeration
- Transcritical variation – A logical and manageable step
- Flooded and DX Transcritical choices
- Ice Rinks and Blast Freezers
- Transcritical should be considered as an option along with low charge Ammonia systems
- R404a HFC use with caution – Legislation coming down the tracks. Don't create liabilities
- CO_2 Compressors getting bigger – 1,700,000 BTU/hr (500 kW) Racks - feasible and cost effective
- Decide on technology with a **life cycle** assessment of the application using local climate analysis – *no one size fits all*