New Copper-based heat exchangers for alternative refrigerants

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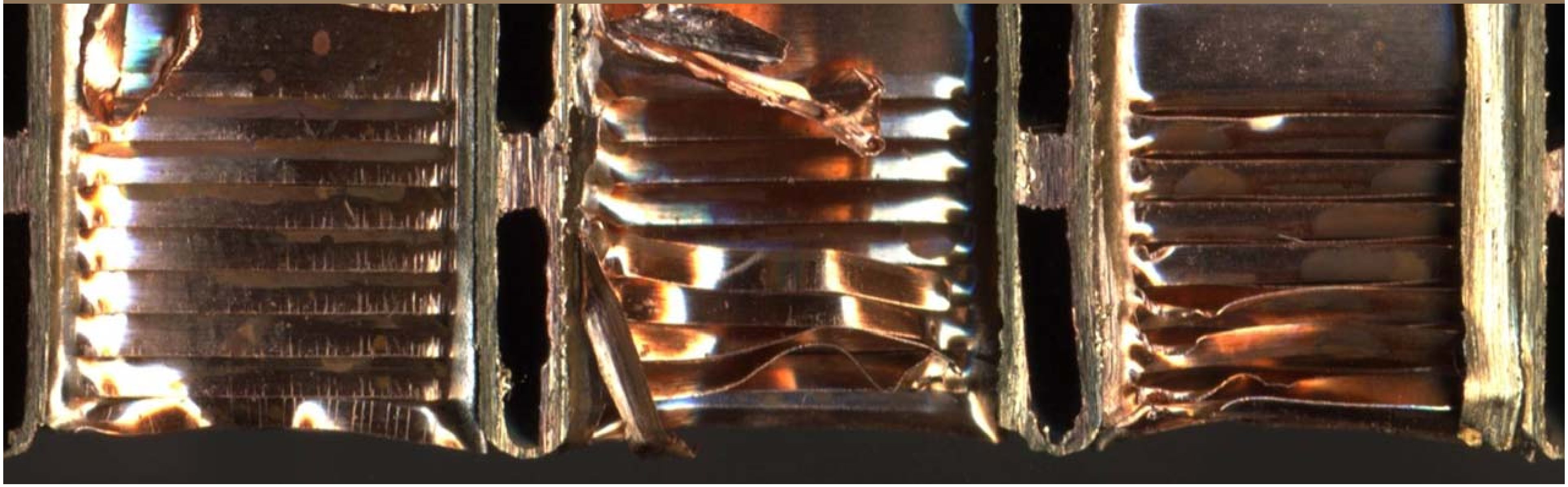


Scope

- Copper tube heat exchanger technologies with advantages for new refrigerants

- Life cycle climate performance (LCCP) impact for systems using copper technologies

Introduction

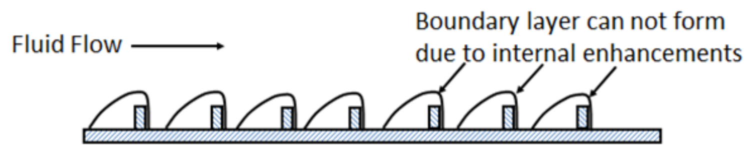
- The important emerging alternative refrigerants:
  - R290 (propane)
  - R744 (CO_2)
  - R32 and R32-HFO blends
- Smooth transition possible to these new refrigerants in room air conditioning and commercial refrigeration systems
  - 4mm, 5mm, and 7mm tube heat exchangers with tailored system design software
  - High strength CuFe2P alloy tube for high pressure system designs with CO_2
  - Copper microchannel tube – next generation option for high pressure, small charge designs for R290 and CO_2

Introduction

- Life Cycle Climate Performance is influenced more by indirect emissions from lifetime operating efficiency than by lower GWP of refrigerant
- All-copper heat exchanger technology can directly address long term efficiency degradation issues caused by mold growth, and enhance LCCP

Round copper tube technology

- Copper tube + aluminum fin modified for greatly enhanced heat transfer:
  - Smaller diameter tube
  - Inner grooving patterns
  - Thinner walls
  - Smaller refrigerant charge
  - Better refrigerant mixing
  - More flexible circuiting to eliminate refrigerant mal-distribution



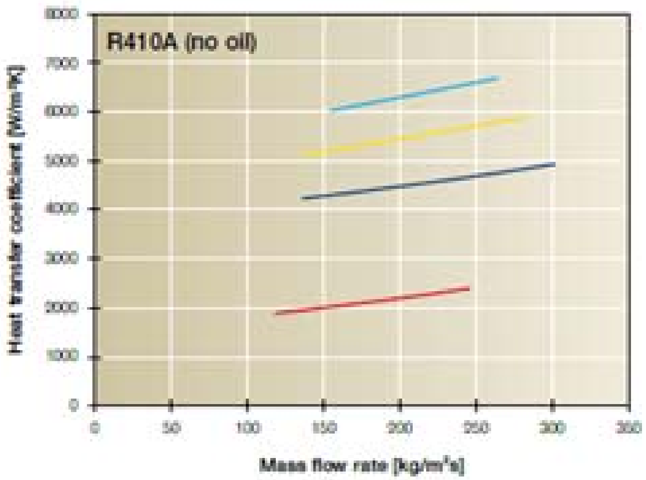
Tubes of 4mm to 7mm diameter

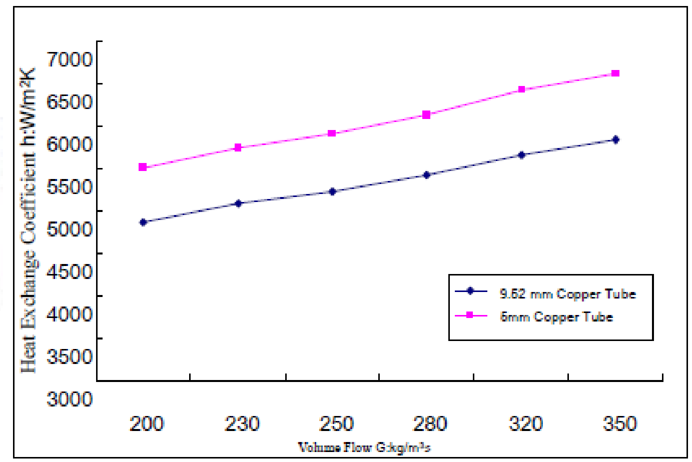
Herringbone pattern grooving

Small diameter tube performance effects

Heat Transfer Technologies

+50% HTC with 2nd generation tube; +100% vs smooth tube using R410A





+20% HTC with 5mm Cu vs 9.53mm tube using HFC refrig.

Test conditions
Condensation - 9.52 mm tubes
t_c = 35 °C
subcooling ~2 K, inlet superheat ~5 K
tube length 2 m

- 2nd generation condensation tube
- Optimized condensation tube
- Standard inner-grooved tube
- Smooth tube

5mm vs 9.53mm tube heat exchanger:

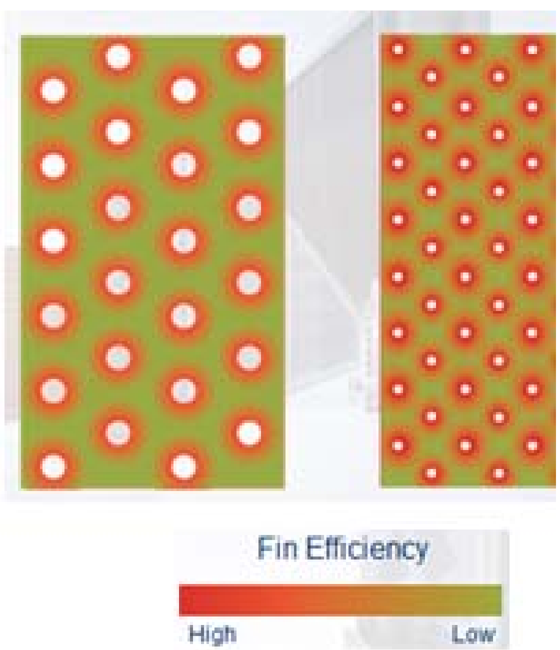
- Up to 50% tube and fin weight reduction
- 50+% reduction in internal volume
- 50% wall thickness reduction
- 50+% HTC enhancement
- 40% reduction in heat exchanger cost

Source: W. Yang et al," Performance and Cost Analysis and Research of Air-Cooled Heat Exchanger using Small Diameter Copper Tubes", Shanghai Golden Dragon Refrigeration Technology, Shanghai 2010; M. Holland,"High Efficiency Microgroove Coils for Commercial and Industrial Applications", Microgroove Technology for Commercial Systems Seminar, ASHRAE Expo, Dallas, Jan. 2013; Wieland Werke,

Effects of fin hole patterns on HTC

Heat Transfer Technologies

- Compounding benefit of small diameter tubes:
  - Greater effective primary fin heat transfer area
  - Higher inside and outside HTC
  - Fins can be downsized for more compact heat exchanger



$Q = \underline{U}\,\underline{A} \times \Delta T$

- A → Less metal required for same effective area (A)
- U → Better inside and outside heat transfer coefficients

Source: M. Holland,"High EfficiencyMicrogroove Coils for Commercial and Industrial Applications", MicrogrooveTechnology for Commercial Systems Seminar, ASHRAE Expo, Dallas, Jan. 2013

Copper microchannel tube heat exchangers

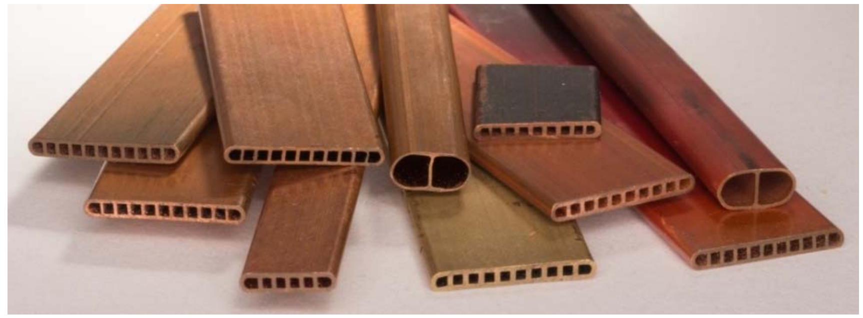
Heat Transfer Technologies

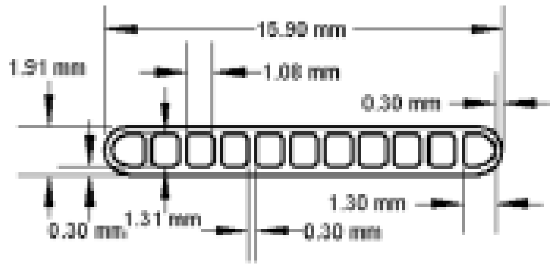
- Produced by hot extrusion
- Precision, thin-wall, 0.2-0.3mm
- Multichannel copper profile, 1.0-1.3mm channel width
- Up to 62 MPa burst pressure with 0.4mm wall and 1mm channels
- Especially attractive for high pressure (17 MPa) and temperatures (180°C) of CO_2

Maximum pressure was determined from:

$$p_{\max} = \frac{2}{\sqrt{3}}\bar{\sigma}\left[\frac{w_0}{t_0}\exp\left(\sqrt{3}\bar{\varepsilon}^*\right)+1\right]^{-1}$$

$\bar{\sigma}$, the true stress, is a function of true strain, $\bar{\varepsilon}$





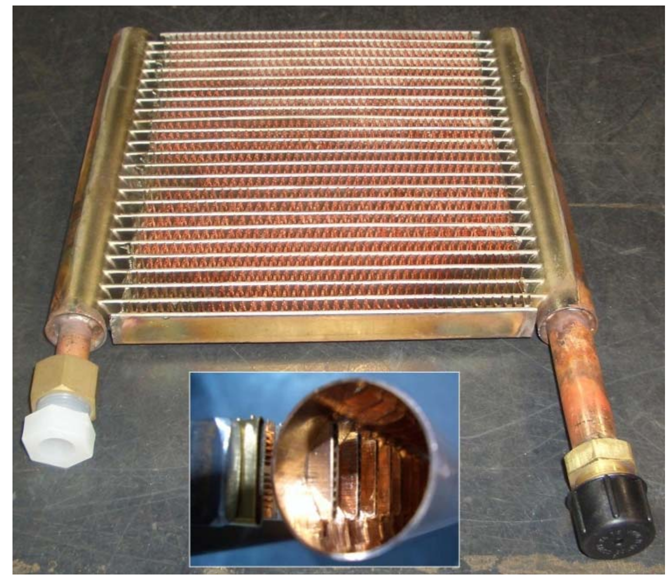
Burst pressures predicted for tubes of 1mm channel width and 0.3mm wall thickness:

UNS C12200 copper:	**47.6 MPa**
AA 3102 aluminum:	18.6 MPa
AA 3003 aluminum:	26.9 Mpa

Source: F.F. Kraft, H.S. Miller, "Failure pressure model and validation for aluminum R744 micro-channel tube", VTMS 8 Conference, Nottingham, UK, May 20-24, I. Mech. E. and SAE, 2007; L. Qi, "Mechanical Behavior of Copper Multi-Channel Tube for HVACR Systems", MS Thesis, Ohio University, Athens, Ohio, 2013

Copper microchannel heat exchanger

- High pressure HXs using CO_2
- Compact high performance HXs for military applications
- Gas to water HX for circulating water refrigerant split systems
- Brazed HXs for demanding environments
- All-copper antimicrobial HXs
- Water heating heat pumps



Advantages

- High thermal conductivity
- More compact HXs feasible due to higher strength and conductivity
- Ability to be in contact with water
- Better long-term durability and general resistance to corrosion
- Lower cost of maintenance when metal-work is required
- Ease of joining and field repair

R32 systems

- R32 is a near drop-in replacement for R410A, with higher cooling capacity (+13%) and efficiency (+2%)
- Higher system pressure and higher compressor discharge temperature
- Ideal for small diameter copper tube HX designs
- 30% reduction in tube diameter, 40% reduction in compressor cylinder volume, and total volume reduction potential 15%

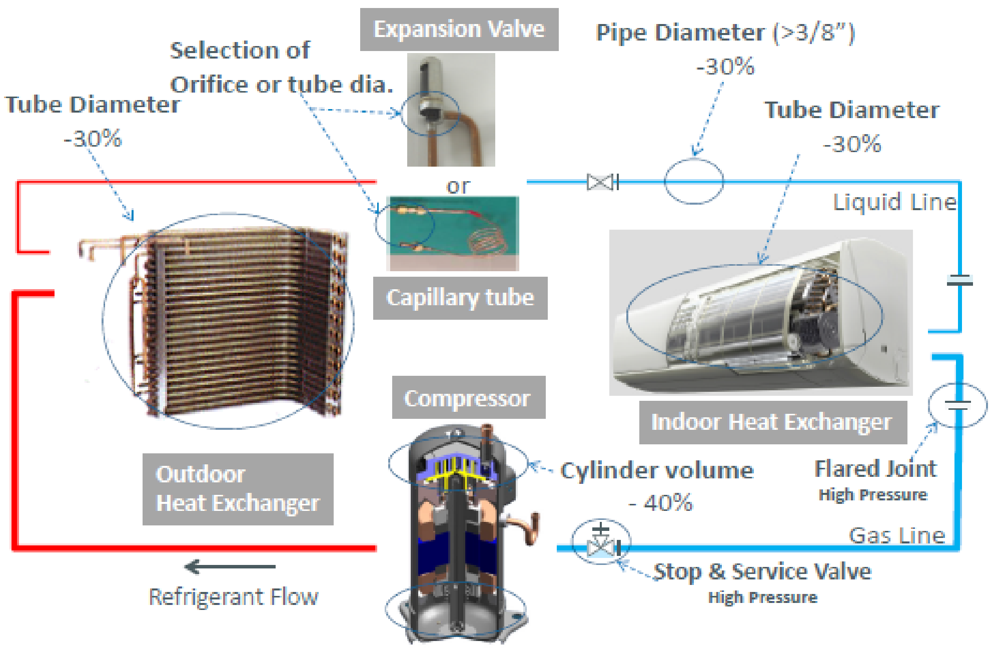
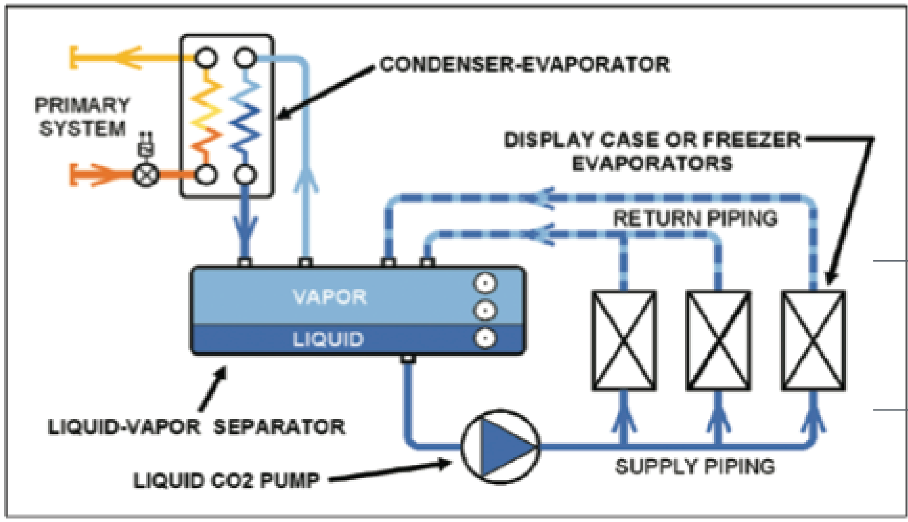


Figure indicates the various changes to compressor size and tubing diameters using R32

Source: M.Dieryckx, "Next Generation Refrigerants—A Daikin Perspective," 2nd Regional Symposium, Alternative Refrigerants for Air-Conditioning Industry in High-Ambient Temperature Countries; the Way Forward, Oct 17, 2012

CO_2 refrigeration systems

- Pumps circulate liquid CO_2 through a smaller refrigeration device (like a display case) at the required case temperature
- Ideal for thinner-wall CuFe2P high-strength alloy copper piping that is significantly smaller than in traditional Direct Expansion systems, at lower cost



Potential for thin-wall CuFe2P copper piping for liquid CO_2

Low Temp secondary loop system using liquid CO_2

Source: Hill Phoenix

CO_2 refrigeration systems

Piping and insulation cost reduction using copper tubing

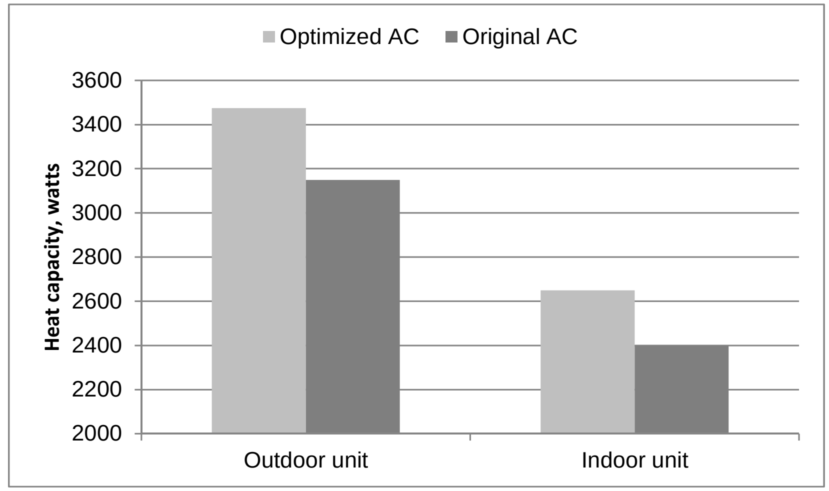
- Cascade systems show 42% cost reduction
- Secondary loop systems show 83% cost reduction

System	Length	Diameter	Insulation	Costs
Direct Expansion (copper tubing)	100m 100m	32mm 10mm	10mm -	100%
Secondary Refrigerant System (plastic tubing)	200m	32mm 10mm	30mm	167%
CO_2 Secondary Refrigerant System (copper tubing)	100m 100m	18mm 6mm	30mm 10mm	83%
CO_2 Cascade System (copper tubing)	100m 100m	18mm 6mm	10mm 5mm	42%
Additional costs not included: fittings, insulation Additional costs for CO_2 : extended pressure range or 2nd defrost system				

Source: U. Hesse, "Secondary Refrigerant Systems for Supermarket Application with Brine or Carbon Dioxide," International Refrigeration and Air Conditioning Conference at Purdue University, 1996, p.372, 374

R290 (propane) for mini-split systems

- Compact HX design using 5mm tube in a 2,600W mini-split
- Refrigerant charge reduced 50% in indoor unit, 45% in outdoor unit, 36% overall
- Increased heat transfer coefficient leads to improved EER with the optimized small diameter copper tube HX design



	Original Design	Optimized Design
Refrigerant charge, gm	390	250
Cooling capacity, watts	2,600	2,537
EER, w/w	3.05	3.20
Heating capacity	2,757	2,786
COP, w/w	3.42	3.44
Indoor Unit Heat Capacity, watts	2,403	2,625
Outdoor Unit Heat Capacity, watts	3,183	3,430
Condensing temperature, °C	46.5	44.1
Evaporating temperature, °C	7.9	9.8

Source: W. Zheng, R. Weed, J. Hipchen, "Developing Low-Charge R290 Room Air Conditioners by Using Small Diameter Copper Tubes", pre-publication manuscript, Copper Development Association

Key applications for copper technologies

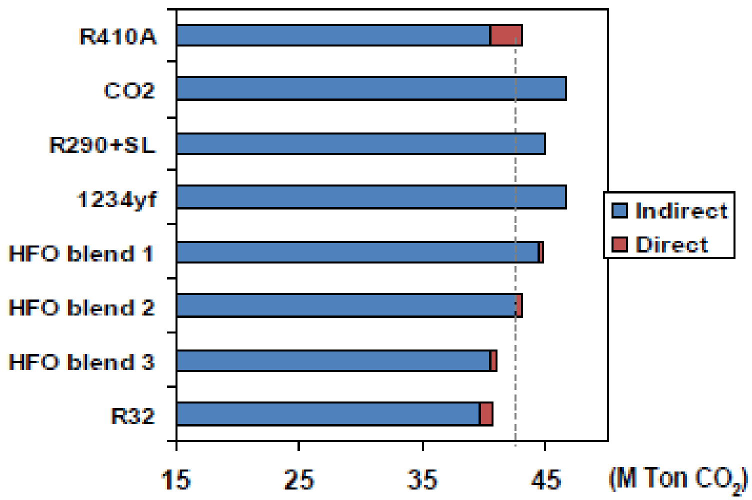
Heat Transfer Technologies

Refrigerant	Application	Copper tube synergies
R32 (and R32-HFO blends)	Residential Unitary AC Commercial AC Heat pump water heaters and Chillers	Small diameter inner-grooved copper tube and Cu MC HXs for reduced charge, higher pressure resistance; All-copper HX stops mold growth
R290 (propane)	Residential AC: Small mini-split systems	Small diameter round tube or Cu MC HXs for 40 - 50% reduced charge (<150gm) compact HX; Brazed joints avoid leaks; All-copper HX stops mold growth
	Commercial refrigeration: Small display cabinets, Bottle coolers, Ice cream freezers	Small diameter round Cu tube or Cu MC HXs for 40 - 50% reduced charge (<150gm) compact HX; Brazed joints avoid leaks; All-copper HX stops mold growth
	Residential/Commercial AC Medium to large size heat pumps	
R744 (CO_2)	Commercial refrigeration: Supermarket transcritical systems	High pressure system needs small diameter Cu tube; High strength CuFe2P alloy tube compact HX; Copper microchannel HX; All-copper HX stops mold growth
	Commercial refrigeration: Supermarket cascade, secondary loops, liquid CO_2 pumps	
	Residential heat pump water heaters (Eco Cute type)	P and T resistance via small diameter Cu tube, high strength CuFe2P alloy tube compact HXs; Copper microchannel HX; All-copper HX stops mold growth

HX = heat exchanger

Refrigerant choice has a relatively small effect on LCCP

- Refrigerants affect TEWI/ LCCP (red) but much less than indirect factors(blue)



	Efficiency	GWP	TEWI
R410A	13.0 SEER	2088	43.1
CO2	-13%	1	46.5
R290+Sec Loop	-10%	3	45.0
HFO-1234yf	-13%	<1	46.6
HFO Blend 1	-9%	150	44.7
HFO Blend 2	-5%	300	43.0
HFO Blend 3	0%	400	41.1
R32	2%	675	40.6

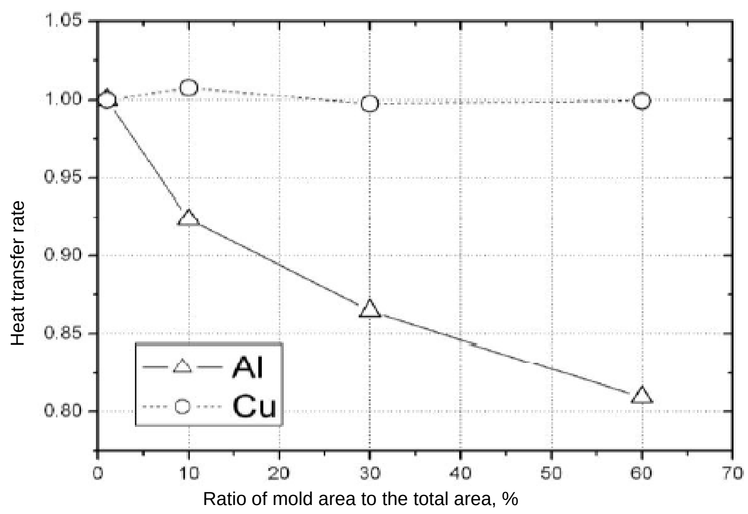
2% Annual Leak Rate
0.65 Kg CO2/ kwh
15 Years Life Time

Source: H. Pham, H. Sachs, "Next Generation Refrigerants: Standards and Climate Policy Implications of Engineering Constraints," ACEEE Summer Study on Energy Efficiency in Buildings, 2010

Reducing mold growth has a large positive impact on operating efficiency and LCCP

Heat Transfer Technologies

- Mold buildup cuts efficiency
- **No change in efficiency with all-copper** vs 19% decline with aluminum fin as mold growth reaches 60% of total heat exchanger area
- Important to maintain efficiency throughout system operational lifetime



Source: G. Ding, "Comparative Study of the Long-Term Performance of Copper and Aluminum Fin-and-Tube Heat Exchangers," Report V to International Copper Association, 2007

Copper-based heat exchanger technologies

Heat Transfer Technologies

- Can enable a smooth transition to alternative refrigerants
- Provide synergies with key performance characteristics of these refrigerants
- Improves total heat transfer performance with additive benefits from both internal surface enhancement and diameter reduction
- Ability to significantly downsize systems for low charge, compactness via either small diameter round tube or copper microchannel
- High strength CuFe2P alloy tube in small diameters and Cu microchannel HX meet the needs for high pressure more compact CO_2 systems
- Improves LCCP by mitigating impact of energy efficiency degradation over A/C operating life due to mold growth

Thank you

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Heat Transfer Technologies