Optimization, Cost and Health Benefits of Copper Tube Plate Fin Heat Exchangers

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Who are we?

Optimized Thermal SYSTEMS

Optimized Thermal SYSTEMS

Serving the HVAC&R industry through cutting edge research, state-of-the-art software, and performance measurements and verification new technologies that can reduce energy consumption and address growing environmental concerns.

Cu Copper Development Association Inc.

Defend and grow markets for copper based on its superior technical performance and its contribution to a higher quality of life worldwide. Members include copper mining and fabricating companies

Heat Transfer Technologies

Providing heat exchanger design, prototyping and manufacturing assistance for the HVAC&R industry with a focus on materials, joining methods, and novel designs.

Presenters:

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- *University of Maryland* (2018)
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Yoram Shabtay

- M.S., Mechanical Engineering
- *Natal University* (1995)
- HTT President since 2008
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Contents

- Introduction
- Benefits of Copper
  - Health benefits: antimicrobial properties and reduced fouling
- Evolution of Copper-Tube Fin Heat Exchangers
  - Benefits of smaller diameter tubes
- Recent Research for 5mm and 3mm Heat Exchangers
- Cost Model
- Conclusions and key takeaways

Introduction

Background

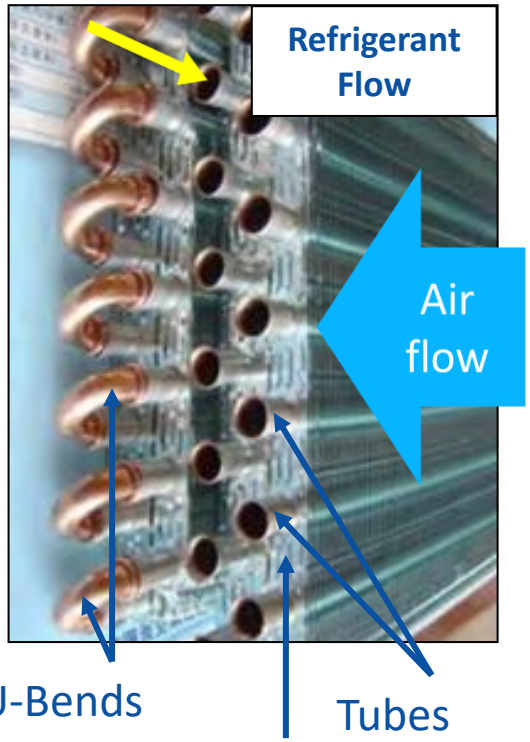
Previous Webinars

All Webinars are available on OTS website:

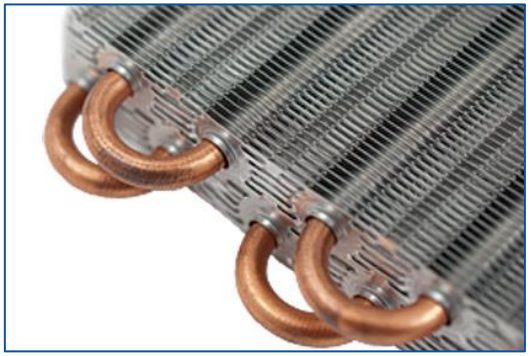
1. Advantages of Small Diameter Copper Tube Fin Heat Exchangers
2. Construction of Small Diameter Copper Tube Fin Heat Exchangers
3. Effective Design of Small Diameter Copper Tube Fin Heat Exchangers
4. Optimization, Cost and Health Benefits of Copper Tube Plate Fin Heat Exchangers
5. Copper Tube Heat Exchangers for Alternative Refrigerants
6. Small Diameter Copper Tube Fin Heat Exchangers and the Impacts of Frost

Heat Exchangers: Air-to-Fluid Tube-Fin

Parts and Working fluids



Copper Tubes, Aluminum Fins

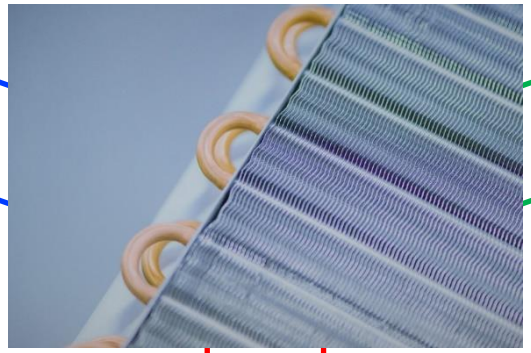


Copper Tubes, Copper Fins

Motivation: what drives heat exchanger design?

Energy Efficiency

- Energy consumed in buildings
  - COP
  - Billing Cost
  - Primary energy use
  - CO_2 emissions
- Partial load



Environment and Safety

- Direct refrigerant emissions
- Footprints (e.g. CO_2, end-of-life equipment)
- Material (resources)

Cost

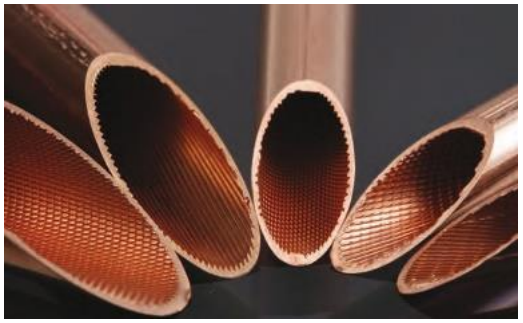
- Material
- Tooling
- Size / Weight

Benefits of Copper

Background

Copper Tubes

- High thermal conductivity → low wall thermal resistance
  - Copper: ~380 W/m·K, Aluminum: ~237 W/m·K, SS: ~15 W/m·K
- Corrosion and biofouling resistance
- Antimicrobial properties
- Refrigerant compatibility
  - All refrigerants except for ammonia



- Soft and pliable → ease of inner grooving
- Small diameter – thinner walls and less charge
  - Lower thermal resistance
  - Withstands higher pressure with thinner walls (essential for CO2 systems) due to lower hoop stress
  - Reduced material cost

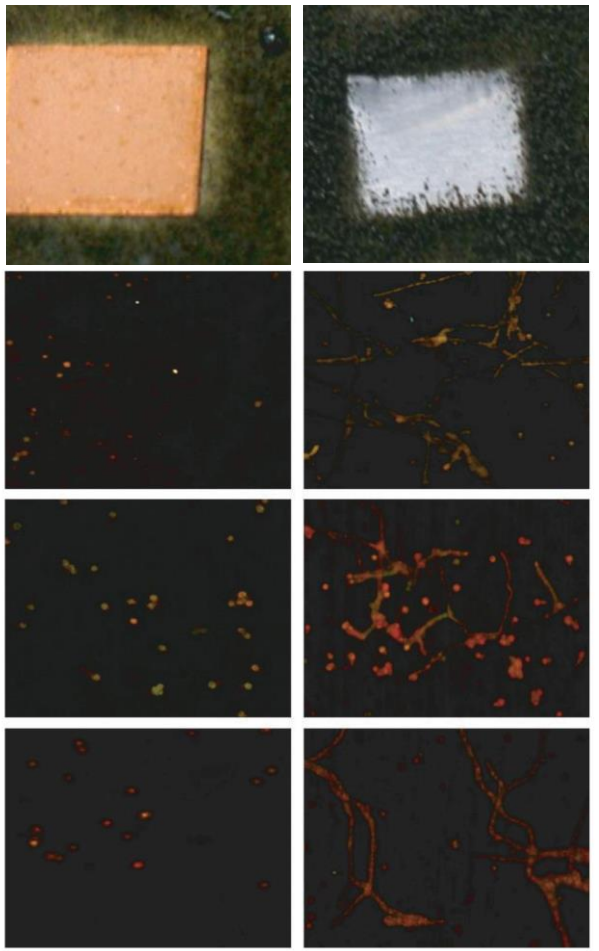
Copper Fins

- Improved efficiency over aluminum
  - Aluminum: 237 W/m·K
  - Copper: 380 W/ m·K
- Reduced biofouling
- Value proposition depends on the application

Antimicrobial benefits

Antimicrobial Properties of Copper

- Copper suppresses the growth of bacteria and molds
- EPA Registration 82012-7:
  - EPA granted a “Treated Article Exemption.”
  - HVAC manufacturers can make product protection claims by suppressing the growth of bacteria and molds that reduce system efficiency and cause product deterioration or foul odors



Source: Weaver et al, The Society for Applied Microbiology, Letters in Applied Microbiology 50 (2010) 18-23

Ft. Jackson SC Barracks Study

- **Copper heat exchangers were found to significantly reduce airborne fungal concentration in both room and supply air when compared with aluminum assemblies**

Fort Jackson Barracks, SC

	LSM Concentrations of Culturable Fungi (CFU/m^3)					
	Room			Vent		
Season	Cu	Al	Al/Cu	Cu	Al	Al/Cu
Heating	131	281	2.1	108	254	2.4
Cooling	305	392	1.3	345	456	1.3
Cooling/Heating	2.3	1.4		3.2	1.8	

Source: Feigley et al, Copper Heat Exchangers for Improving Indoor Air Quality: Cooling Season at Fort Jackson

New England Middle School Study

- All-copper heat exchanger replaced a copper tube / aluminum fin unit
- Study compared 3 AHU:
  - AHU #4: UV lights and existing copper tube/aluminum fin coils
  - AHU #5: No UV lights and new copper tube/copper fin coils
  - AHU #6: No UV lights and existing copper tube/aluminum fin coils
- Results showed bio-growth was successfully controlled by copper tube/copper fin coils, even without the use of UVGI (ultraviolet germicidal irradiation)

Antimicrobial Effects, Conclusions

Conclusions

- Copper suppresses fouling of coils without the use of UVGI
- Copper heat exchangers significantly reduce airborne fungal concentrations in both room and supply air when compared with aluminum assemblies

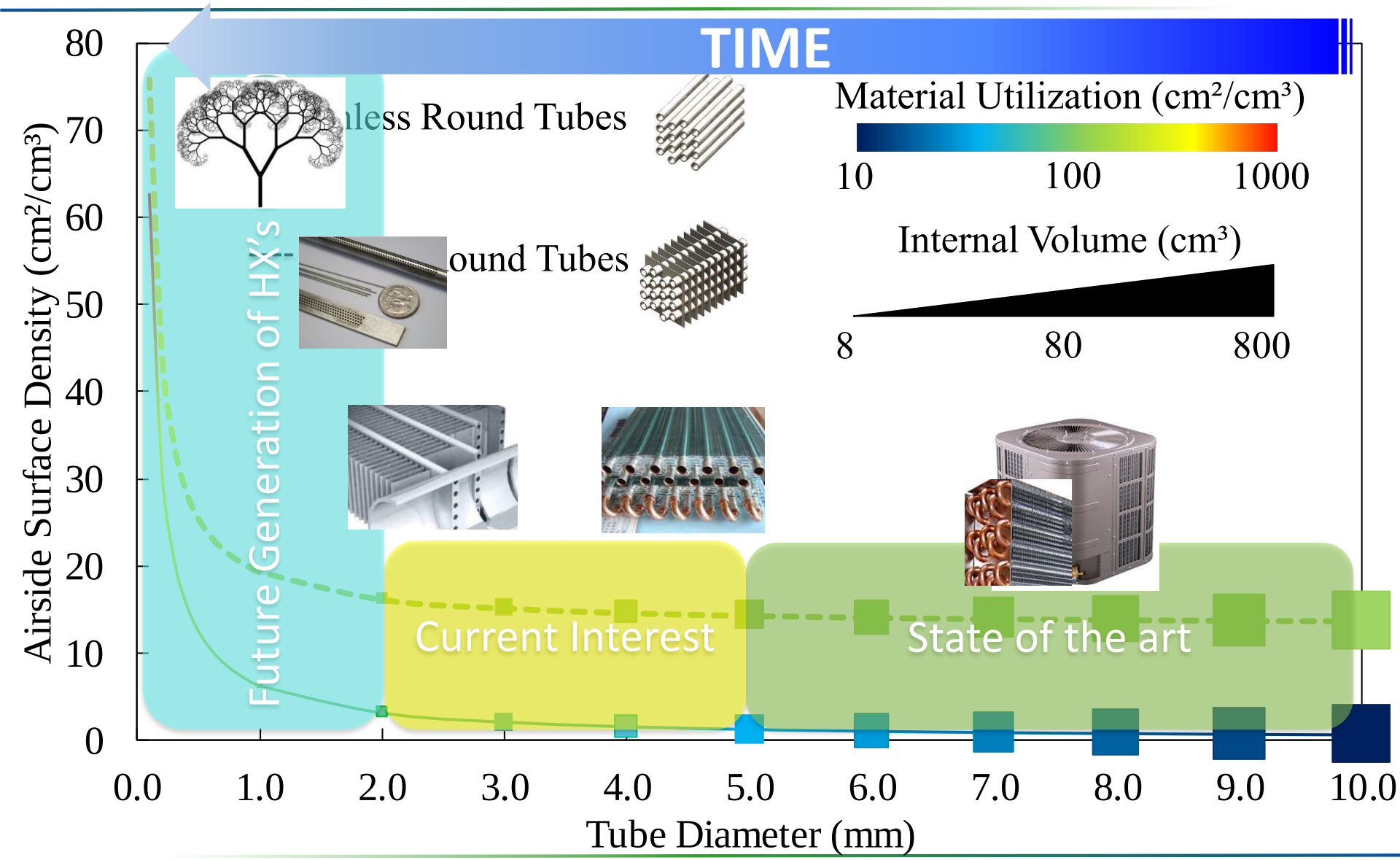
Potential Benefits

- Reduced energy consumption due to anti-fouling maximization of airflow
- Reduced energy consumption from elimination of UVGI equipment
- Reduced maintenance for cleaning coils
- No maintenance of UVGI equipment

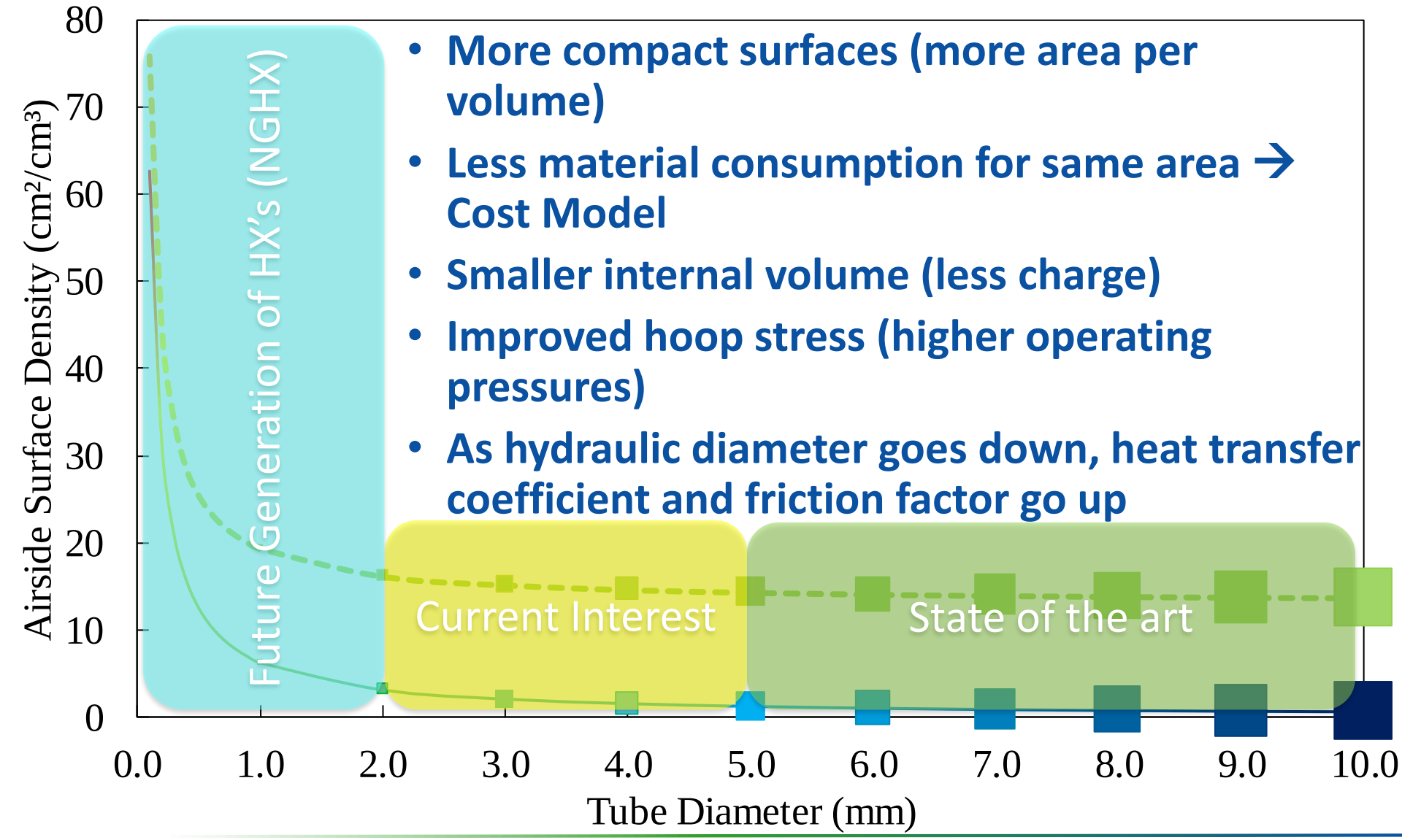
Evolution of Copper-Tube Fin Heat Exchangers

Background

First Order Analysis



Fundamentals of Smaller Tubes



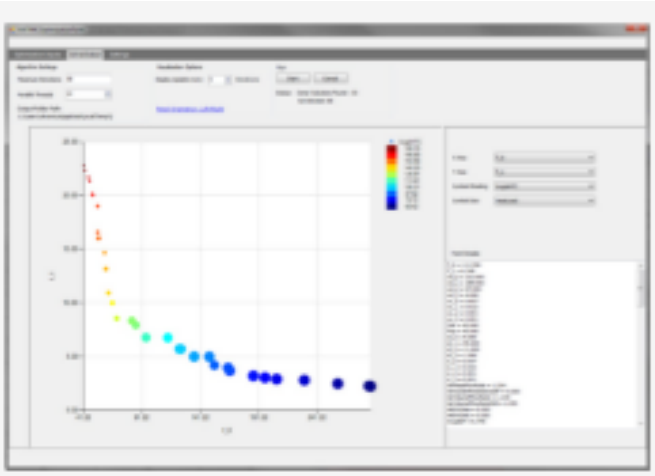
- More compact surfaces (more area per volume)
- Less material consumption for same area → Cost Model
- Smaller internal volume (less charge)
- Improved hoop stress (higher operating pressures)
- As hydraulic diameter goes down, heat transfer coefficient and friction factor go up

CoilDesigner® - Webinar 3

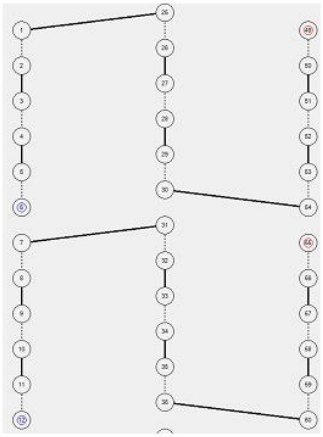
Optimized Thermal SYSTEMS

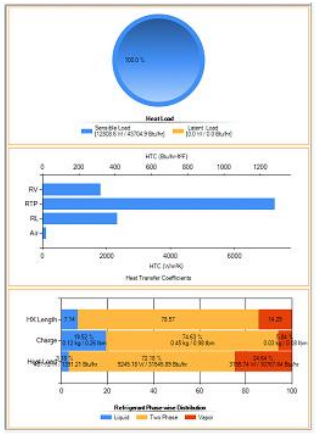
CoilDesigner® is a highly customizable software tool that designs, simulates and optimizes the performance of a variety of heat exchangers. This unique tool helps to shorten product development timeframes and associated costs. With one integrated tool, you can design your product, simulate its performance, and optimize it for multiple objectives (e.g. cost, efficiency, and power consumption.

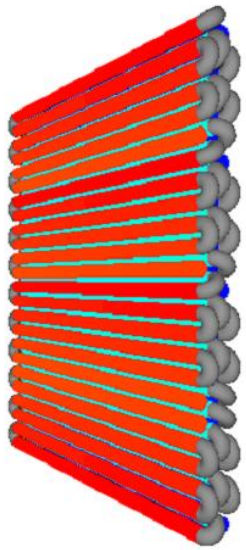
CoilDesigner® now includes a range of correlations for tubes < 5mm!

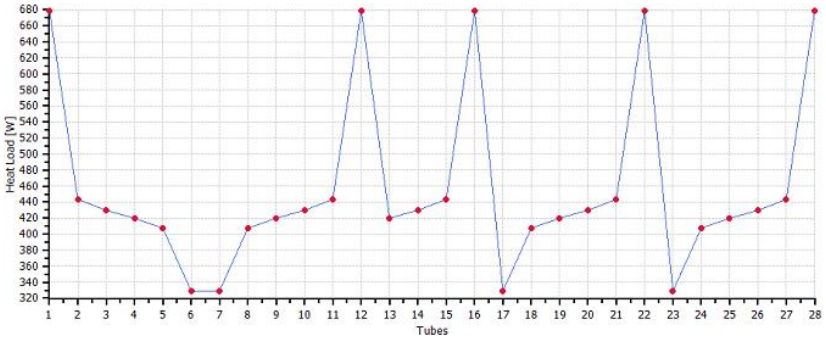


Optimization and Parametric Analysis!









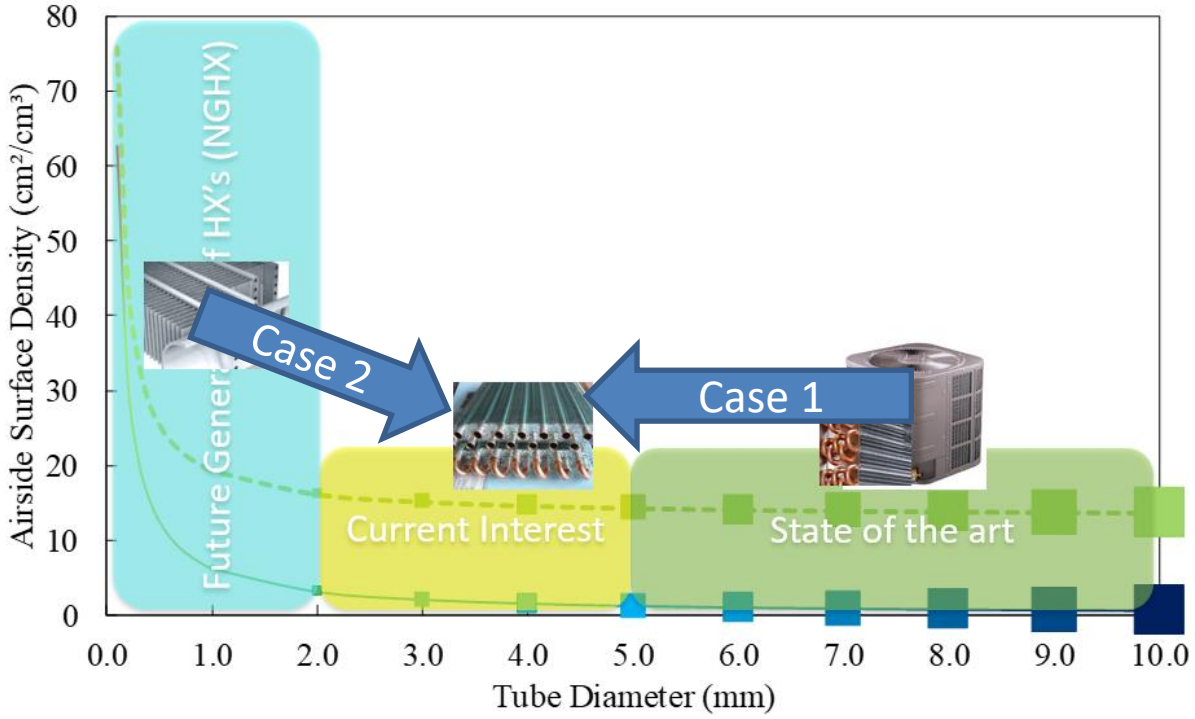
Request a free trial at optimizedthermalsystems.com

3mm and 5mm Heat Exchangers

Case Studies

Case Study Introduction

- **Case 1: Water Heater Study: replace 7.94mm (5/16”) tube evaporator for residential Heat Pump Water Heater (HPWH) with 5mm tube evaporator**
- **Case 2: Major USA HVAC OEM: replace microchannel condensers with 3 to 5mm tube condensers**



Case 1: HPWH Introduction

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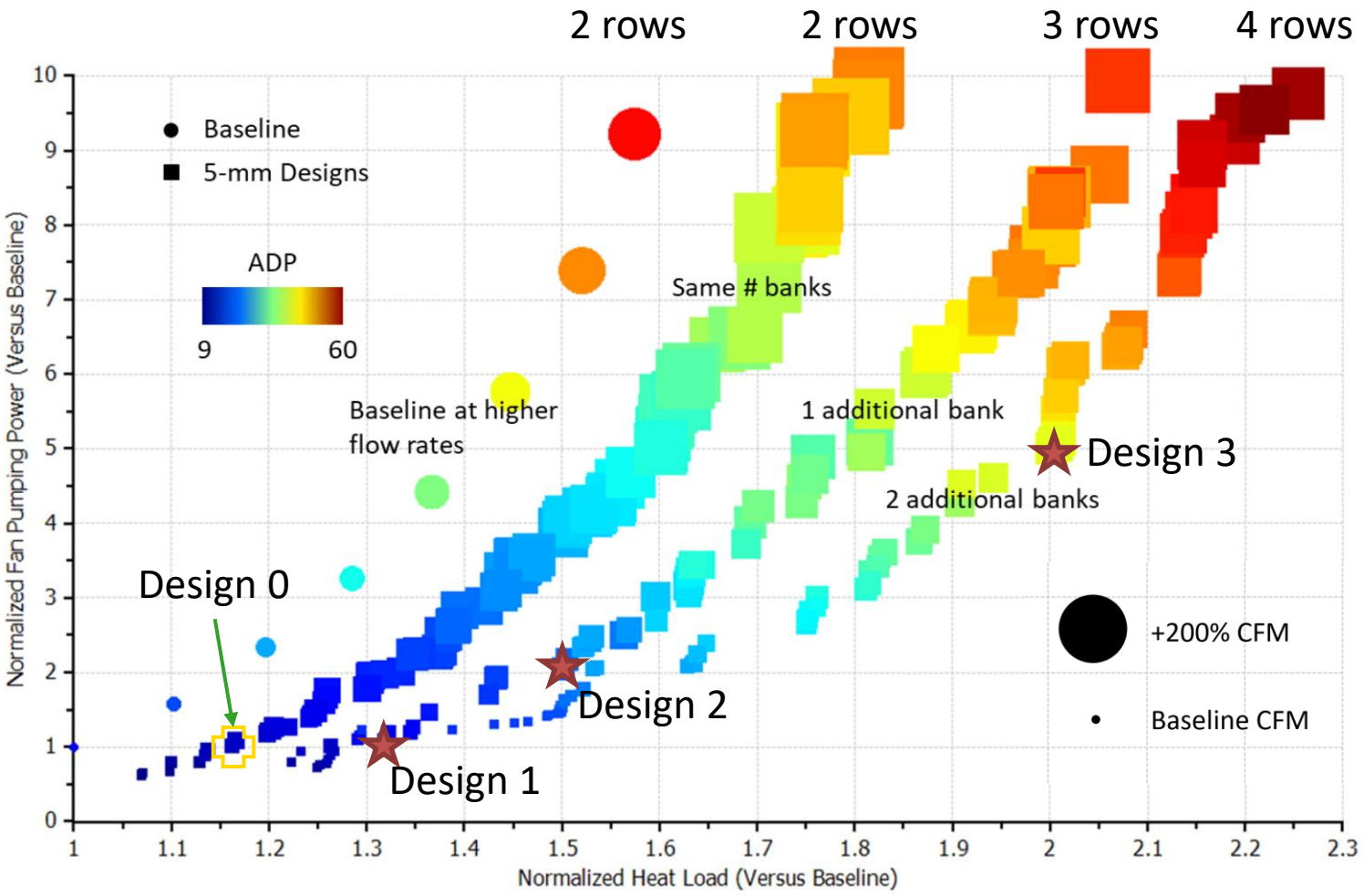
Goal: Increase evaporator capacity of residential heat pump water heater

- Evaporator size is limited by the equipment enclosure
- Existing coil is a tube-fin hx with 7.94mm (5/16”) copper tubing and aluminum louvered fins
- Optimization goal: maximize heat load capacity while minimizing fan power

HPWH Pareto Comparison



5mm evaporators deliver 30 – 40% more capacity than the 7.94mm baseline design

HPWH Summary

Parameter	Design 0 % Change	Design 1 % Change	Design 2 % Change	Design 3 % Change
Number of Tube Banks	+0%	+50%	+50%	+100%
Number of Tubes per Bank	+38%	+38%	+38%	+38%
Coil Volume	-	+11%	+11%	+48%
Number of Circuits	+200%	+350%	+350%	+350%
Fin Material Mass	+11%	+51%	+52%	+126%
Tube Material Mass	-+19%	+22%	+22%	+63%
Air Flow Rate	+26%	+14%	+54%	+83%
Refrigerant Mass Flow Rate	+16%	+31%	+50%	+100%
Heat Load	+16%	+32%	+50%	+100%
Air Pressure Drop	-19%	-13%	+33%	+174%
Fan Pumping Power	+0%	+0%	+104%	+401%

Customer plans to build and test a 5mm prototype coil like Design 1

Major HVAC OEM: Introduction

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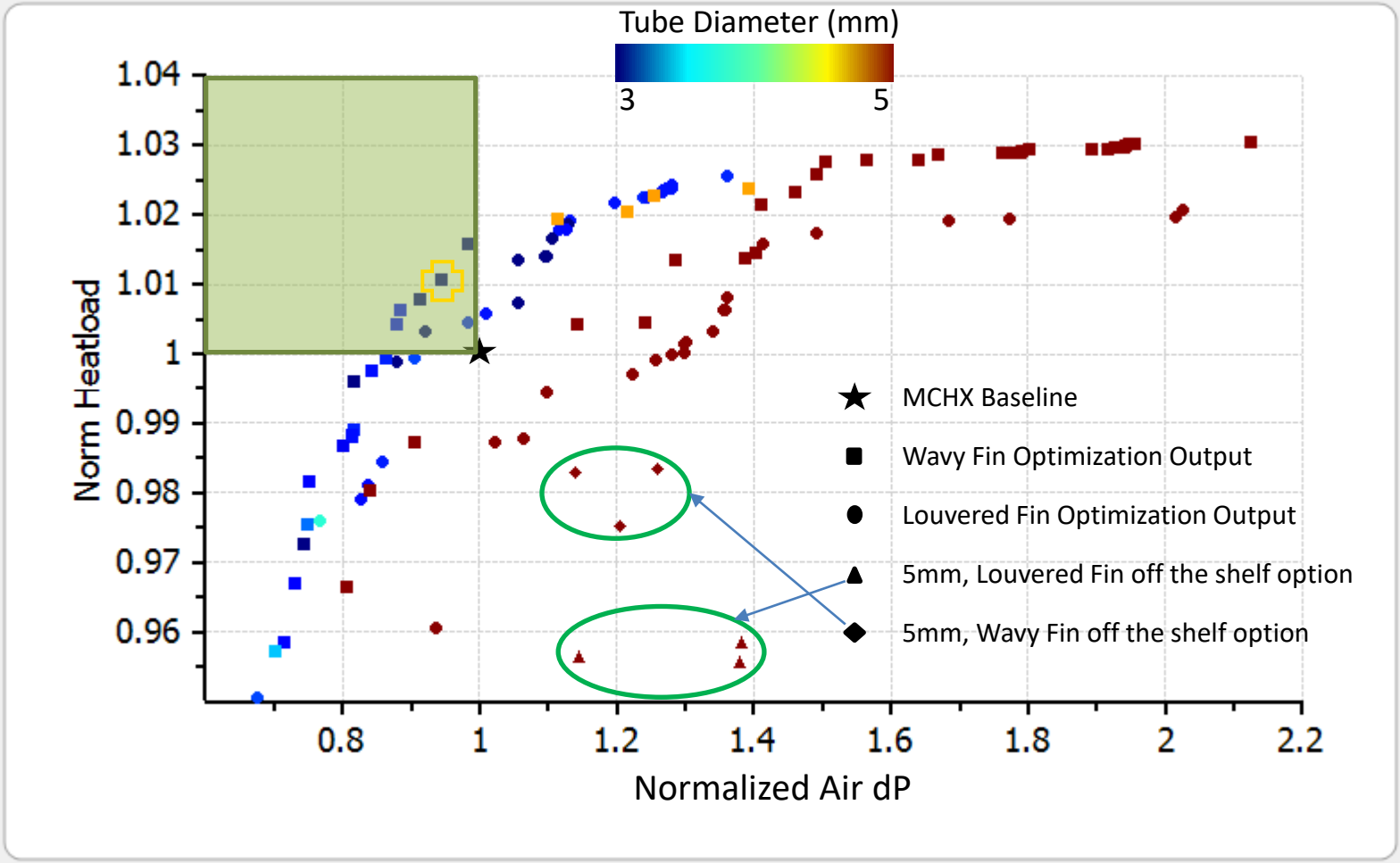
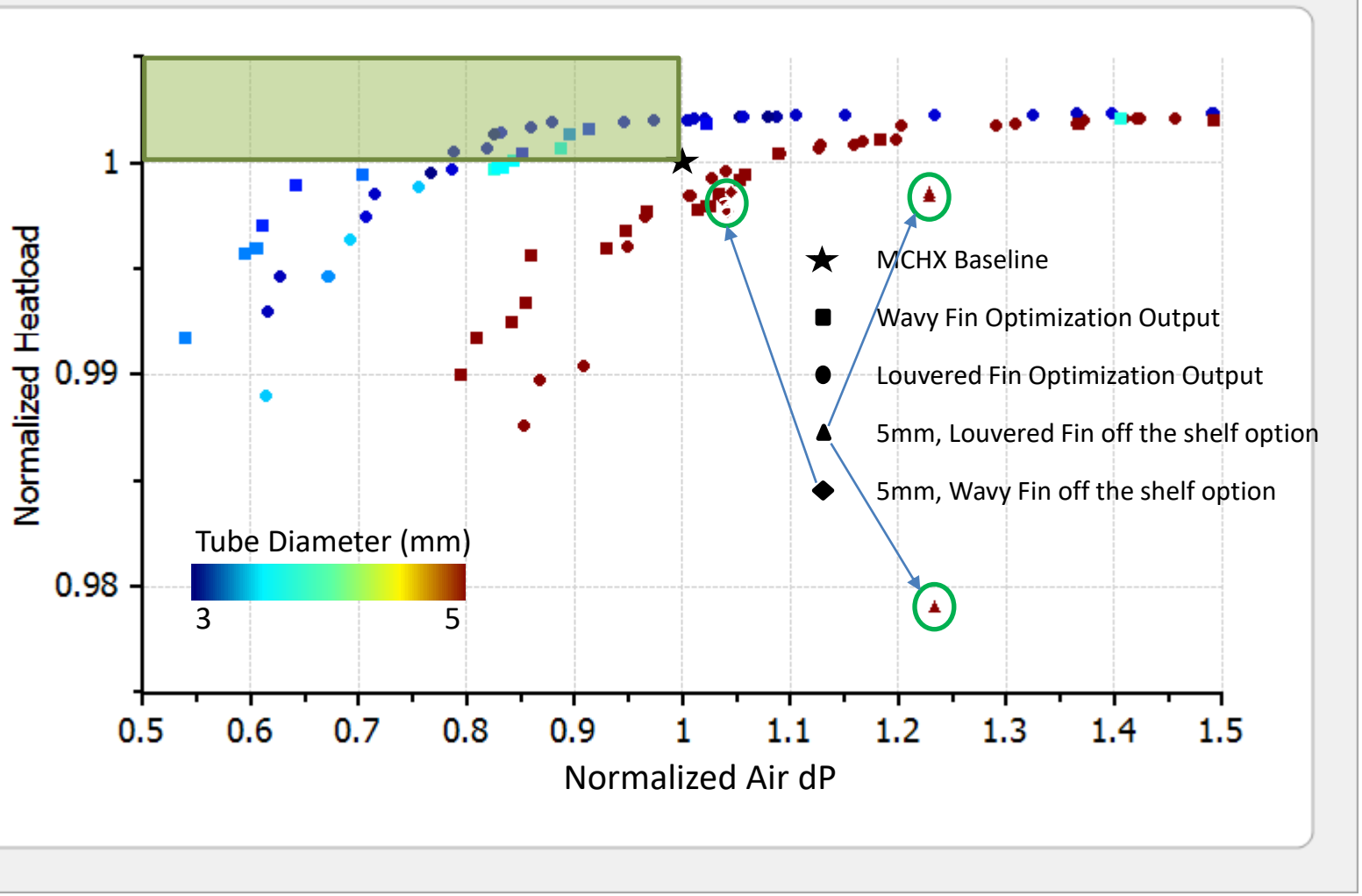
Goal: Replace microchannel HX (MCHX) for heat-pump condenser with 3 – 5mm tube-fin HX

- MCHX is purchased from a third-party supplier and OEM wants to produce HX in-house
- Two condensers:
  - Residential 2-ton system
  - Commercial 10-ton system
- Constraints for drop-in replacement:
  - Drop-in replacement: height, width, depth, fin density, refrigerant pressure drop and refrigerant charge
- Optimization goal: maximize heat load and minimize air-side pressure drop

OEM: Commercial Pareto Comparison



OEM: Residential Pareto Comparison



Cost Model

Cost Model

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- HTT President since 2008
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Heat Transfer Technologies is a consulting firm specializing in novel heat exchanger design and fabrication process development.
Yoram Shabtay is the founder and President of Heat Transfer Technologies, LLC.
Mr. Shabtay has more than 25 years of experience in heat exchanger design and fabrication using various metals and different joining technologies related to HVAC&R.
HTT helped develop the Microgroove 5mm tube HX technology with the ICA years ago.
Our experience helped in the development of this cost model.

Cost comparison of two case studies will be reviewed next

HX Cost Contributors:

Materials, Nitrogen, Furnace, Labor and equipment CAPEX

Cost Comparisons RTPF vs RTPF and RTPF vs ALMC

December 2020 LME cash prices

Copper	7.964	$/kg	Copper tubing	$10.35	/kg
Aluminum	2.049	$/kg	Aluminum fin	$2.46	/kg
Steel plate	0.77	$/kg	ALMC Extruded tube	$4.24	/kg
Braze Rings for Copper	0.028	$ each	Alibaba BCuP-7 for AC $28/kg for 10-99kg) ~1g per ring		
Flux-core Braze rings	0.01	ea.	Alibaba Al88Si12 Aluminum Flux Cored Rings brazing wire ER4047		
			Aluminum Clad Round tube	$4.44	/kg
			ALMC and Manifold cost: Trumony Aluminum LTD 1T min.		
			https://zhenghe2019.en.alibaba.com/?spm=a2700.details.cordpanyb.4.2f376641f7F7n1		

Case 0 baseline RTPF evaporator 5/16 tube (2 x 13)				Case 0a design 0 RTPF evaporator 5mm tube (2 x 18)			
26	# tubes	mass [kg]		36	# tubes	mass [kg]	
330mm x 50mm sides		0.09		330mm x 50mm sides		0.09	
Fin: 0.1016mm 15fpi		0.66746	OTS data	Fin: 0.11mm 20fpi		0.74250	
Tube: Cu 7.9375 x		0.55316	OTS data	Tube: Cu 5.00 x		0.45080	
Process:		RTPF cost	labor	Process:		RTPF cost	labor
Operation				Operation			
Copper Tubes		$5.73		Copper Tubes		$4.67	
Hairpin bending			$0.42	Hairpin bending			$0.42
Fin		$1.64		Fin		$1.83	
Fin making			$0.42	Fin making			$0.42
Side Plates		$0.07		Side Plates		$0.07	
Braze ring and placement		$0.73	$0.42	Braze ring and placement		$1.01	$0.42
Assembly			$0.42	Assembly			$0.42
Expansion			$0.42	Expansion			$0.42
U-Bends Flame brazing			$0.42	U-Bends Flame brazing			$0.42
Total		$10.69	$2.52	Total		$10.09	$2.52
Overheads (15%)		$1.60		Overheads (15%)		$1.51	
CAPEX		$0.31		CAPEX		$0.31	
Total+Capex		$12.60			Total+Capex	$11.91	

Materials:

Copper tubing and aluminum fins are LME+30% fab

Cost Comparisons RTPF vs RTPF and RTPF vs ALMC					
December 2020 LME cash prices					
Copper	7.964	$/kg	Copper tubing	$10.35	/kg
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			https://zhenghe2019.en.alibaba.com/?spm=a2700.details.cordpanyb.4.2f376641f7F7n1		

Nitrogen, Furnace and equipment CAPEX

Notes:									
3 years payback period on CAPEX (1.5M MCHX)								Overhead	$0.00
Furnace costs:		Typ.		Typ. Usage cont. furnace			Cost	Capex	$0.51
Nitrogen:		$0.50	/100SCF	2500	SCFH		$0.21	ea	$0.51
Natural Gas		$0.25					$0.25	ea	
						Total	**$0.46**	**Energy + gas cost**	
CAPEX RTPF		1.55					**$0.31**	10 yrs depreciation on 0.5M units /yr	
Capex ALMC		2.55					**$0.51**	10 yrs depreciation on 0.5M units /yr	
In a year there are 525600 minutes so at one core a minute, one furnace and one builder system can produce just over **500,000 MCHX**									
CAPEX RTPF									
Hairpin bender	0.10								
Fin press	0.50								
Fin die	0.05								
Tube expander	0.50								
Tube/fin Assy mach	0.10								
Brazing U-bends co	0.30								
Total	**1.55**								
CAPEX ALMC HX									
Manifold press	0.20	$ Millions							
Fin machine	0.50								
Fin die	0.05								
Tube/fin Assy mach	0.30								
Brazing furnace	1.50								
Total	**2.55**								

Case study 1: 5/16 tube RTPF evaporator vs. 5mm tube RTPF

Case 0 baseline RTPF evaporator 5/16 tube (2 x 13)			
26	# tubes	mass [kg]	
330mm x 50mm sides		0.09	
Fin: 0.1016mm 15fpi		0.66746	OTS data
Tube: Cu 7.9375 x		0.55316	OTS data
Process:		RTPF cost	labor
Operation			
Copper Tubes		$5.73	
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Fin		$1.64	
Fin making			$0.42
Side Plates		$0.07	
Braze ring and placement		$0.73	$0.42
Assembly			$0.42
Expansion			$0.42
U-Bends Flame brazing			$0.42
Total		$10.69	$2.52
Overheads (15%)		$1.60	
CAPEX		$0.31	
Total+Capex		$12.60	

Case 0a design 0 RTPF evaporator 5mm tube (2 x 18)			
36	# tubes	mass [kg]	
330mm x 50mm sides		0.09	
Fin: 0.11mm 20fpi		0.74250	OTS data
Tube: Cu 5.00 x		0.45080	OTS data
Process:		RTPF cost	labor
Operation			
Copper Tubes		$4.67	
Hairpin bending			$0.42
Fin		$1.83	
Fin making			$0.42
Side Plates		$0.07	
Braze ring and placement		$1.01	$0.42
Assembly			$0.42
Expansion			$0.42
U-Bends Flame brazing			$0.42
Total		$10.09	$2.52
Overheads (15%)		$1.51	
CAPEX		$0.31	
Total+Capex		$11.91	

Case study 2: ALMC condenser vs. 3mm tube RTPF

Case 2 baseline commercial MCHX condenser				Case 2a opt RTPF commercial condenser 3.05mm tube (2x68)			
59		mass [kg]		136	# tubes	mass [kg]	
Manifolds Al 32 OD x 1.25 wall 717g/m		1.06	Tube every	2059.83mm x 50mm sides		0.56	
Fin: 21 fpi		8.539	OTS data	Fin: 0.1016mm 21.38 fpi		5.90	OTS data
ALMC 59 32 port tubes		8.504	OTS data	Tube: Cu 3.05 x 0.1211mm		2.80	OTS data
Total weight		18.10					
Process:	$/kg	Aluminium MCHX	labor	Process:		RTPF cost	labor
Operation				Operation			
ALMC Tubes		$36.06		Copper Tubes		$29.02	
Caps		$0.20	$0.08	Hairpin bending			$0.42
Fin		$21.00	$0.42	Fin		$14.50	
Side Plates		$0.51	$0.10	Fin making			$0.42
Manifolds		$4.69	$0.40	Side Plates		$0.43	
Assembly (Auto core builder)			$0.42	Braze ring and placement		$3.81	$0.42
Degreasing	$0.05	$0.91	CAB furnace	Assembly			$0.42
Core fluxing	$0.06	$1.13	CAB furnace	Expansion			$0.42
Core drying	$0.01	$0.18	CAB furnace				
Brazing	$0.05	$0.86	CAB furnace				
Nitrogen	$0.05	$0.95		U-Bends Flame brazing			$0.42
Total		$67.90	$1.42	Total		$50.27	$2.52
Overheads (15%)		$10.19		Overheads (15%)		$7.54	
CAPEX		$0.51		CAPEX		$0.31	
	Total+Capex	$78.60		Total+Capex		$58.13	

Cost Model: Conclusions

Case Study 1	
Baseline (8 mm)	$12.60
Design 0 (5 mm)	$11.91
% Savings	6%

Optimized for heat load and air dP

Case Study 2	
Baseline (MCHX)	$78.60
Optimized Tube/Fin	$58.13
% Savings	35%

Optimized for heat load and air dP

Coming Next

Webinar 5

Copper Tube Heat Exchangers for Alternative Refrigerants

Many alternative refrigerants currently under consideration. How does copper tube fin heat exchanger design need to change when designing for a new refrigerant?

Webinar 6

Small Diameter Copper Tube Fin Heat Exchangers and the Impacts of Frost

As copper tubes get smaller and smaller, the coils get denser and fin spacing gets narrower. This webinar will discuss the magnitude of potential performance degradation from water bridging and frost and explore possible mitigations.

Backup

Optimized Thermal SYSTEMS

THANK YOU!

Contact Information:

Darren Key

- M.S., Mechanical Engineering
- *University of Maryland* (2018)
- Joined OTS in July 2020
- Contact Info:
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- John Hipchen, Annina Hogan, Dale Powell. “Comparison Study of Bio-Growth in Commercial AHU’s Using Copper Heat Exchangers and Components”