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Optimize to Exceed

Cu Copper Alliance™

Effective Design of Small-Diameter Copper Tube-Fin Heat Exchangers

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Speakers

Dennis Nasuta

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  University of Maryland, College Park
- *Joined OTS - 2011*

Daniel Bacellar

- Ph.D., Mechanical Engineering
  University of Maryland, College Park
- *Joined OTS - 2016*

Who is OTS? Who is ICA?

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

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.

Overview

- Introduction
  - Motivation
  - Background
- Heat Exchanger Modeling
  - Fundamentals
  - Introduction to CoilDesigner®
  - Demonstration: modeling a 5 mm heat exchanger
- Applications
  - Validation against experimental data
  - Example of 5 mm design
- Conclusions and Q&A

Introduction

Why Does Heat Exchanger Design Matter?

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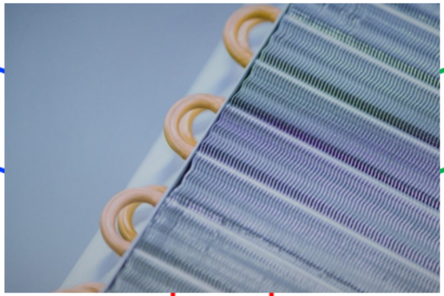

Energy Efficiency

- 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)

Cost

- Material
- Tooling
- Size / Weight

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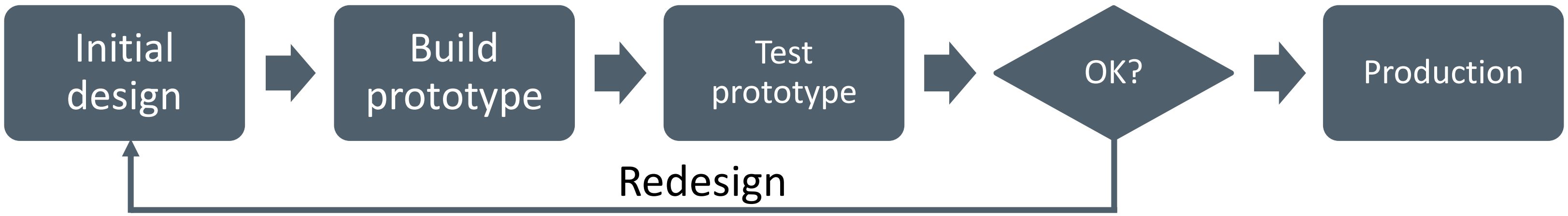
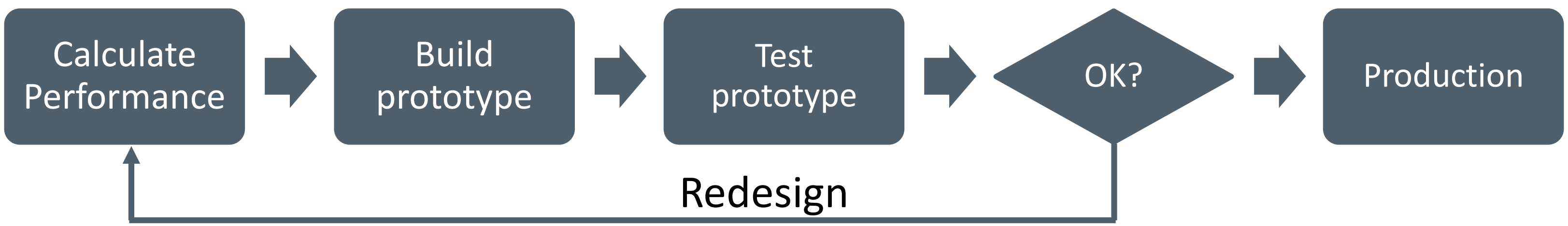
Heat Exchanger Design Techniques

- Trial-and-error

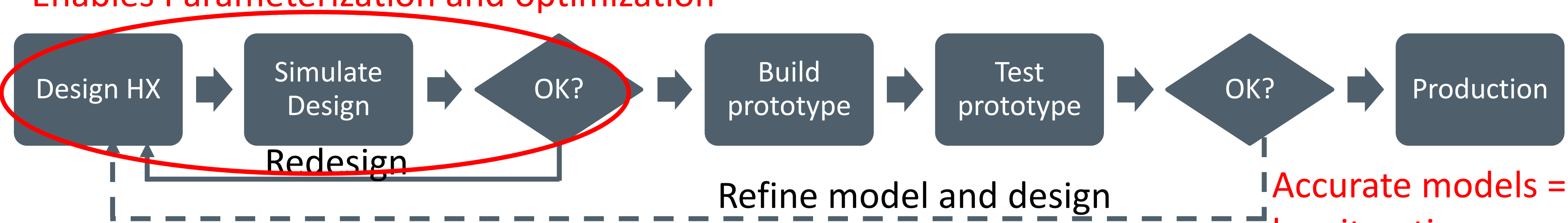


- Hand calculations / rules of thumb



- Simulation/optimization software

Enables Parameterization and optimization



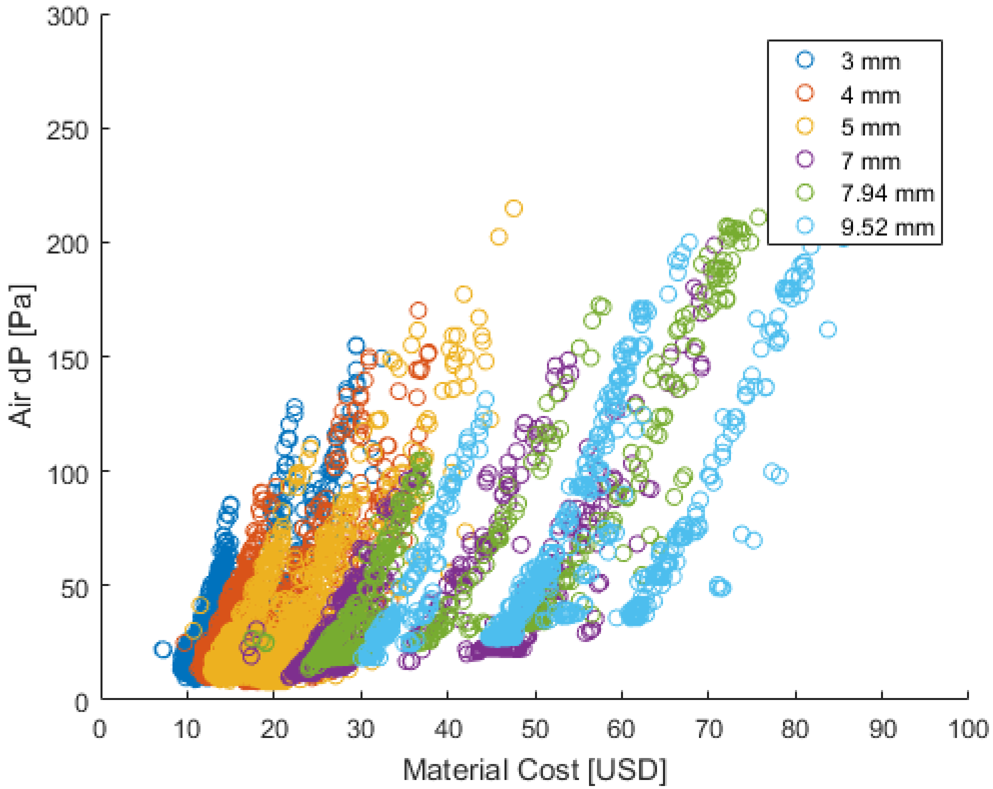
Accurate models = less iteration

HX Design Options

How Many Ways Are There To Design a Tube-Fin Heat Exchanger?

At Least:

- 6 Tube diameters (5 mm, 1/4”, 7 mm, 5/16”, 3/8”, 1/2”)
- 6 fin types (flat, wavy-smooth, wavy-herringbone, slit, louver, wavy-louver)
- 10 Fin densities
- 10 tube lengths
- 10 vertical pitches
- 10 horizontal pitches
- 10 circuitries
- …
- Already 3.6 million designs!



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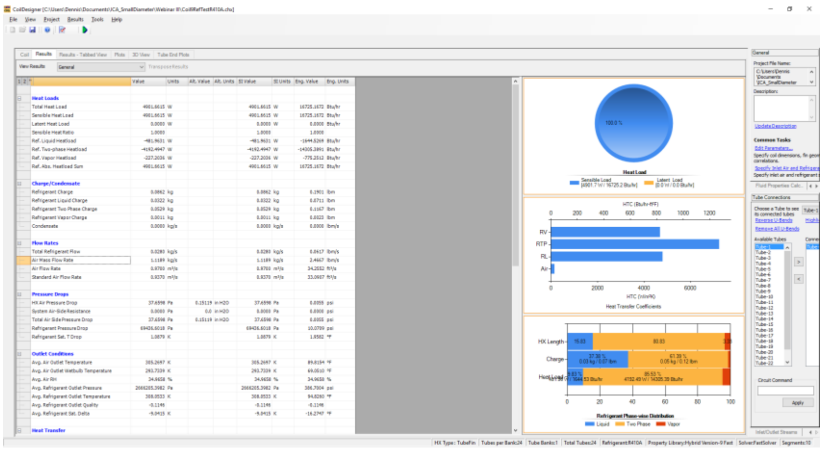
Fundamentals

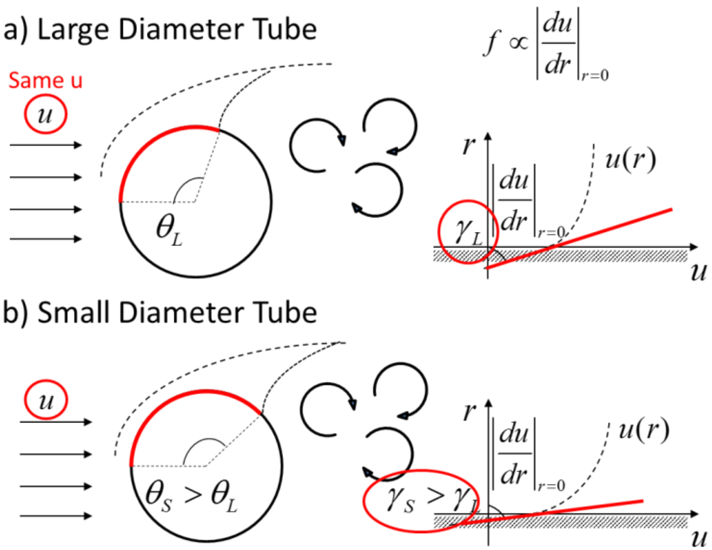
Heat exchanger modeling

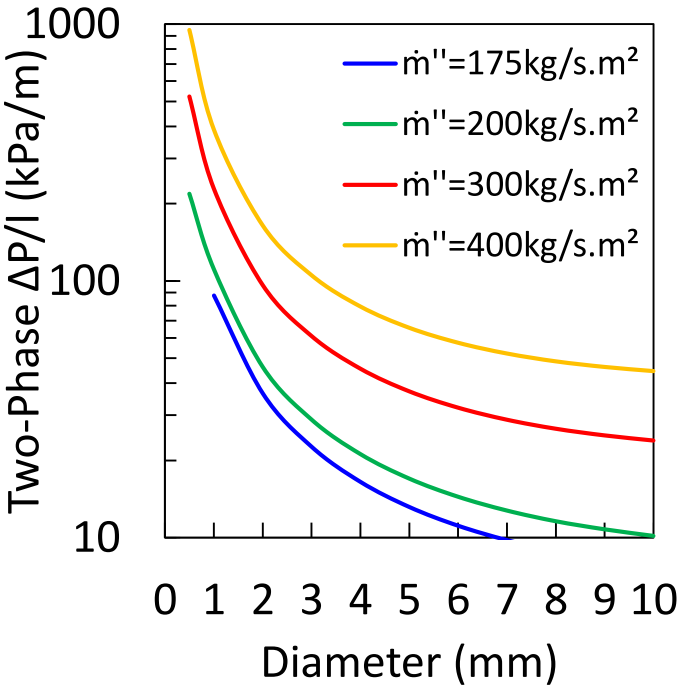
Small Diameter Design Considerations



- Accurate modeling tools

- Air-side pressure drop





- Refrigerant-side pressure drop

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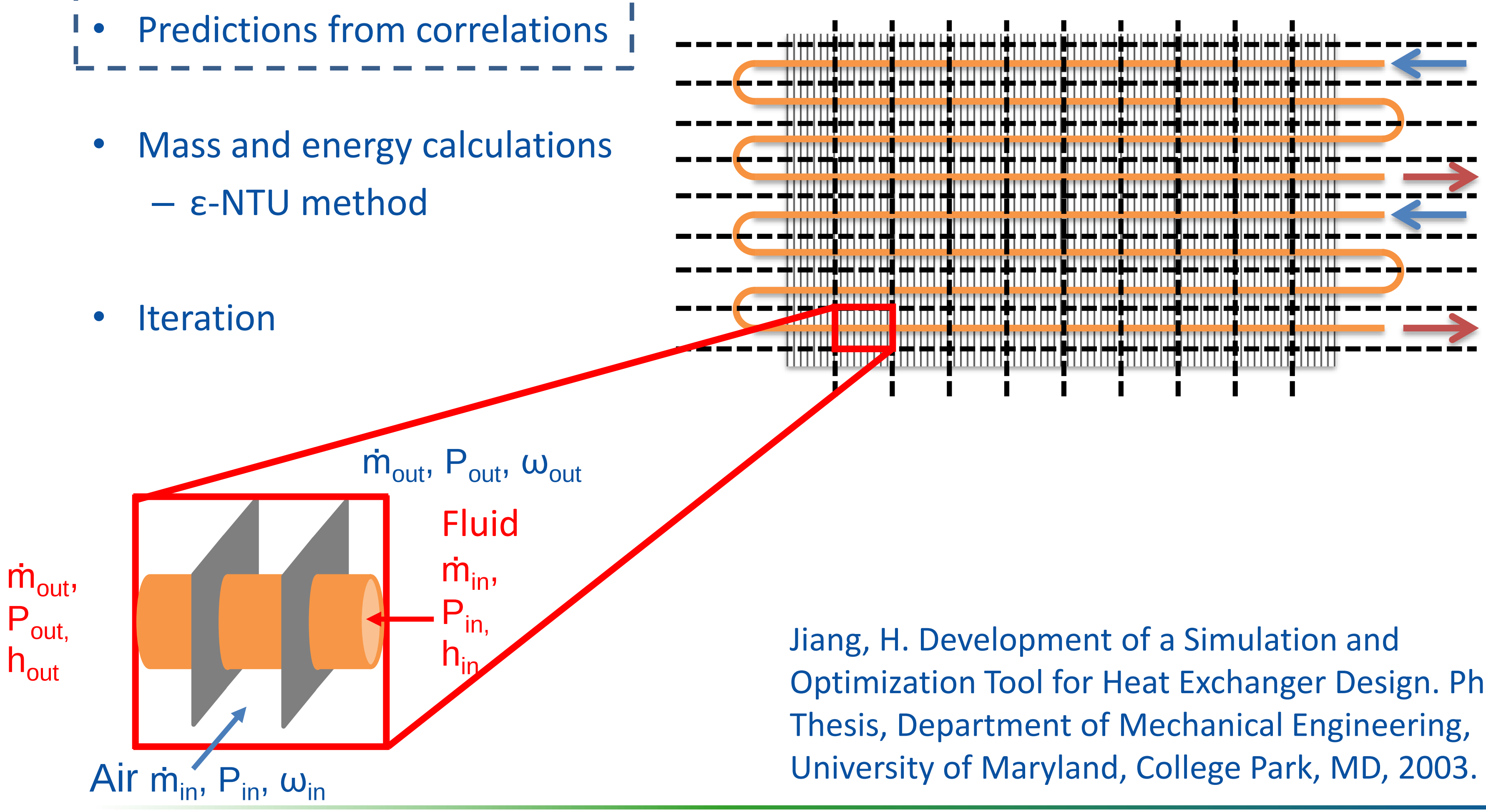
Small Diameter Design Considerations

- Refrigerant Choice
- Material Cost
- Manufacturing Constraints

Modeling Fundamentals

- Finite control volumes
- Predictions from correlations
- Mass and energy calculations
  - ε-NTU method
- Iteration

Heat Exchanger: Face View



Jiang, H. Development of a Simulation and Optimization Tool for Heat Exchanger Design. Ph.D. Thesis, Department of Mechanical Engineering, University of Maryland, College Park, MD, 2003.

Demonstration

Modeling in CoilDesigner®

Example HX – Geometry Details

5 mm Condenser with Louver Fins

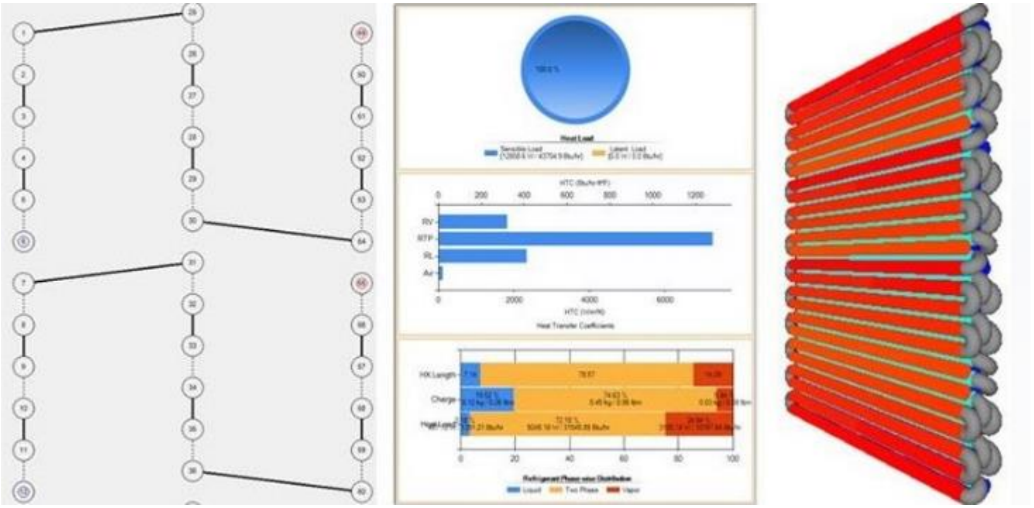
Parameter	Dimension
Tube configuration	1x24
Finned length	547 mm
Tube OD	5 mm
Tube pattern	19.05 x 16.5 mm
Fin thickness	0.1 mm
FPI	15

Example HX – Operating Conditions

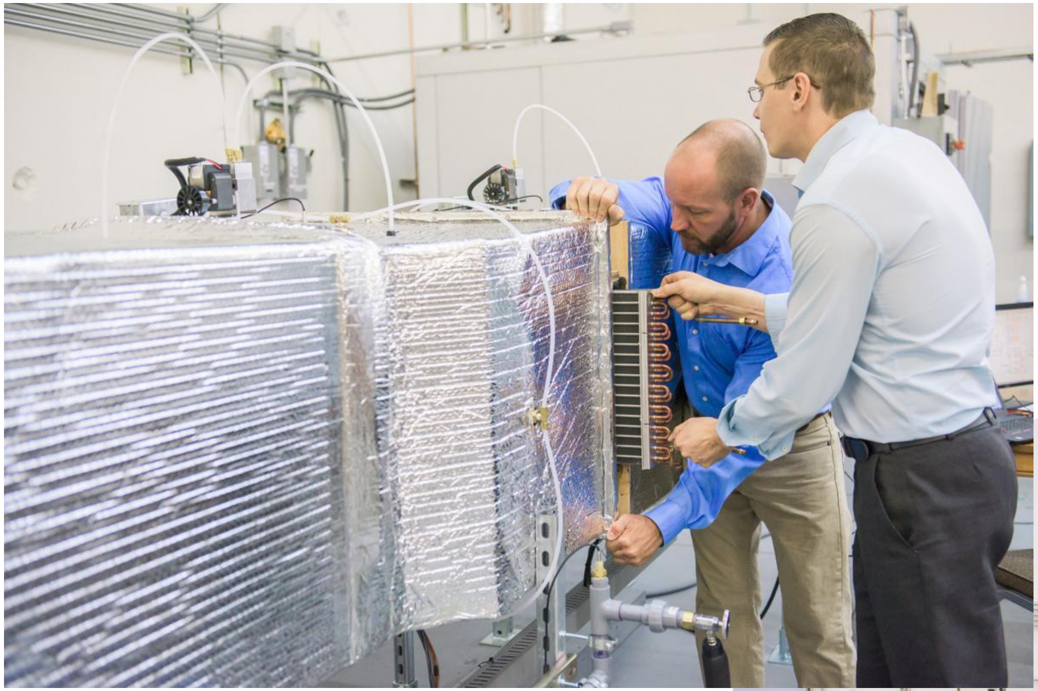
R-410A Testing

Tain	RH in	Air flowrate	Ref P in	Ref T in	Ref mdot
K	%	m3/s	Pa	K	kg/s
301	45	0.97	2,735,642	322	0.028

Input into CoilDesigner®….

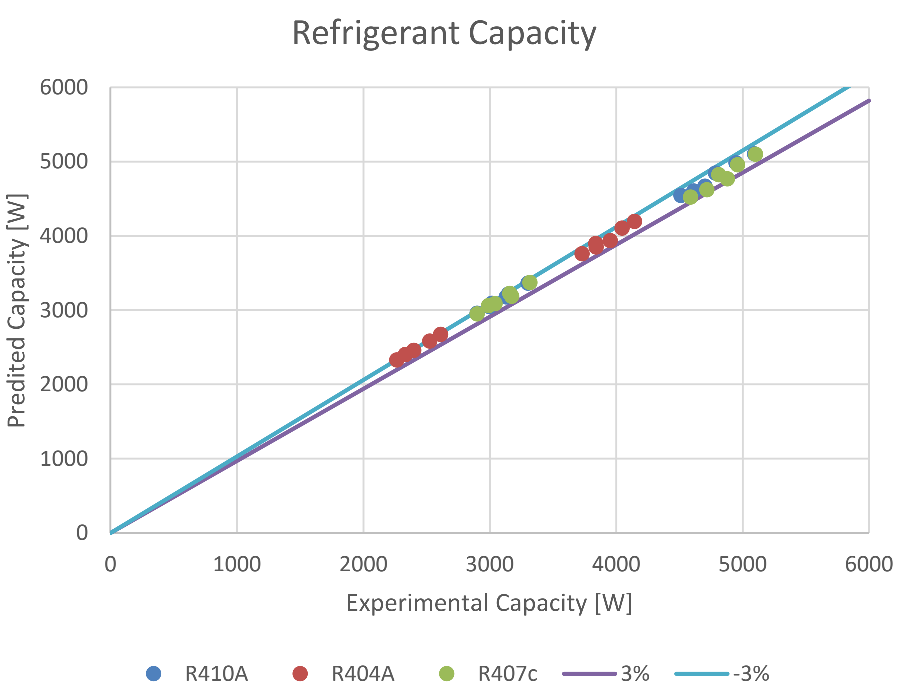


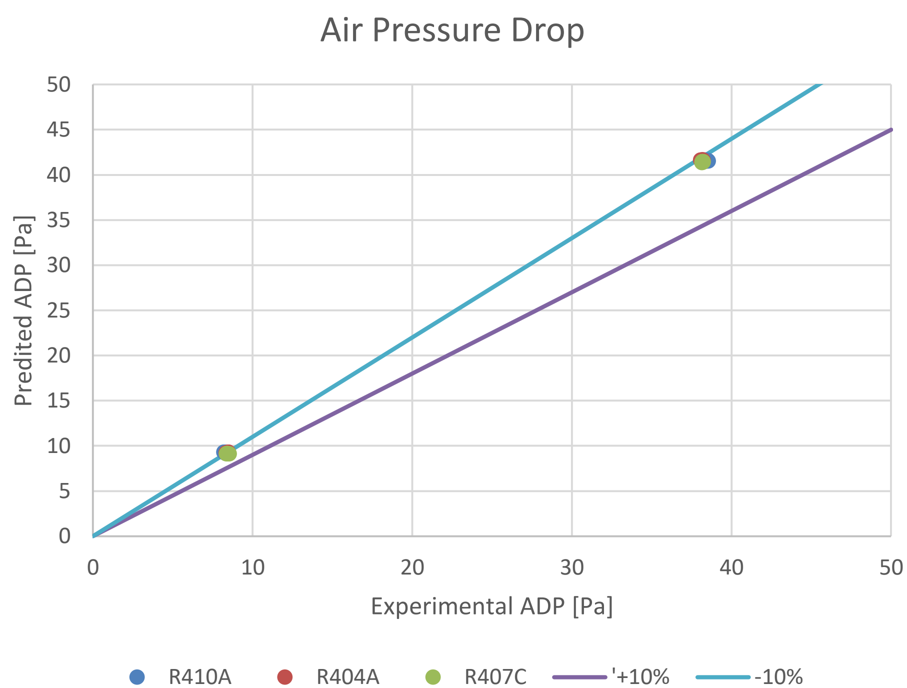
Example HX – Experimental Testing



Example HX – Experimental Results

ADP	Trefout	Prefout	RDP	Taout	Rhaout	Ref capacity	Subcooling coil out
Pa	K	Pa	Pa	K	%	W	K
38.4	310	2,652,371	83271	305	21	4702	6.5





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Applications

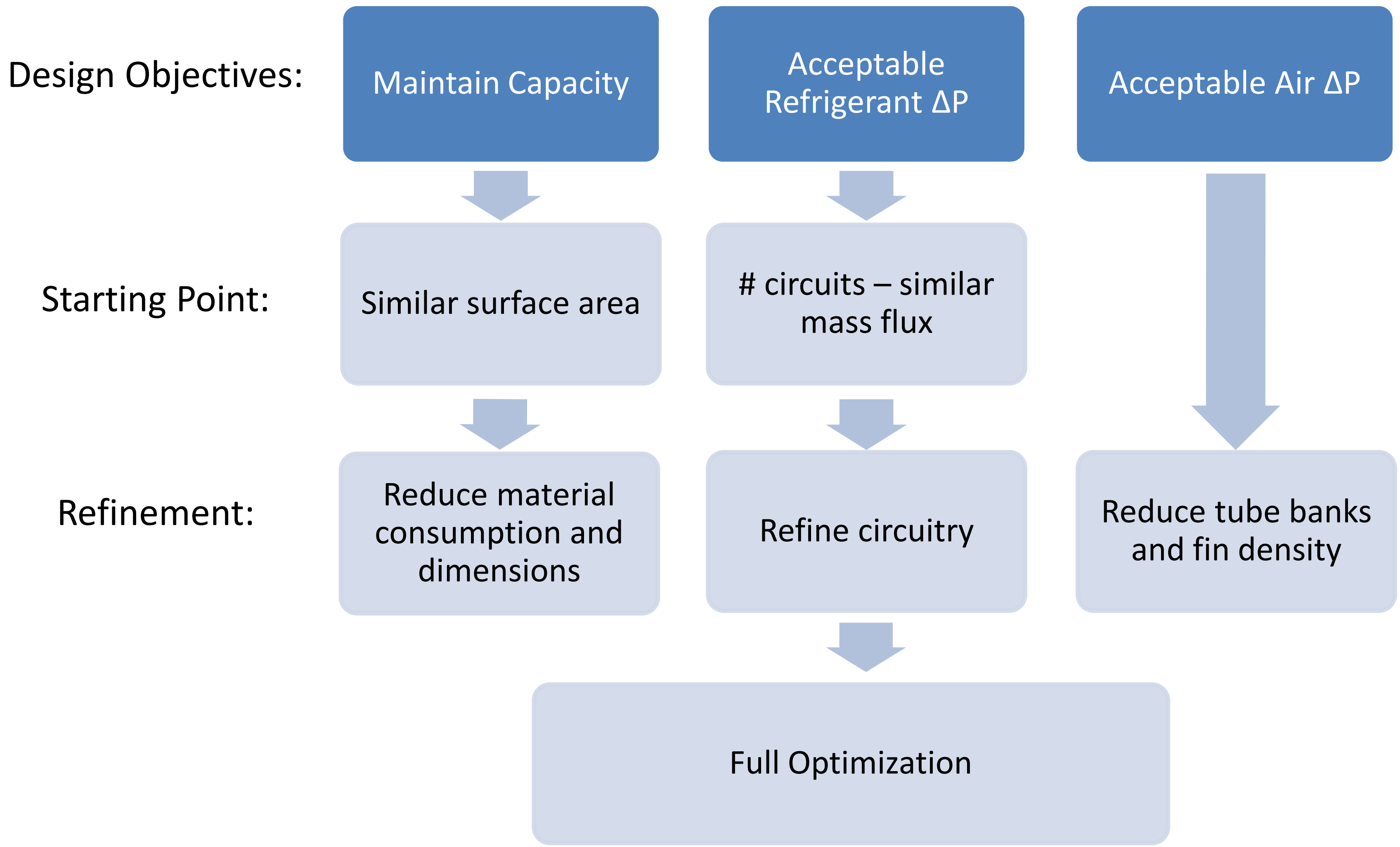
Drop-In Replacement Condenser

- Baseline design:
  - 3/8" OD tubes
  - 2x22 tubes in 1" equilateral stagger
  - 18 fins per inch
  - 700 x 559 x 44 mm

- Requirements:
  - Maintain 4 kW capacity
  - Do not increase air ΔP significantly beyond baseline: 27 Pa
  - Do not increase refrigerant ΔP significantly beyond baseline 6.4 kPa

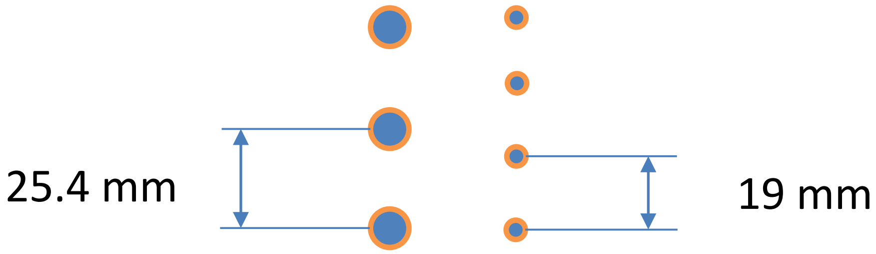
Replace 3/8" tube heat exchanger with 5 mm coil

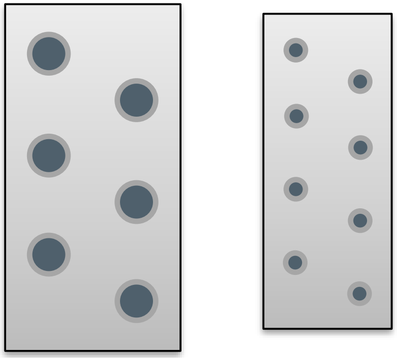
Drop-In Replacement Condenser (2)



5 mm Layout

- Baseline design has 2x22 tubes with 1” vertical spacing
- Typical 5 mm vertical spacing is 19.05 mm:
  – Keep even number: 28 tubes vertically
- Baseline fin density is 18 FPI
  – External heat transfer area is 22.6 m^2
  – 2-row 5mm pattern requires 24 FPI to achieve equivalent surface area
  – 3-row 5mm pattern meets this surface area with 16 FPI

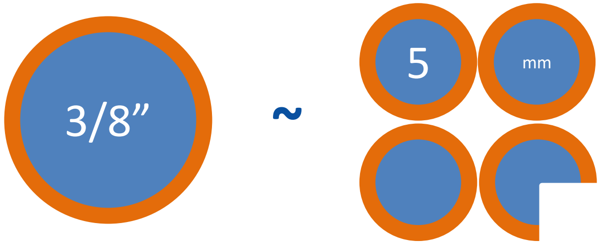


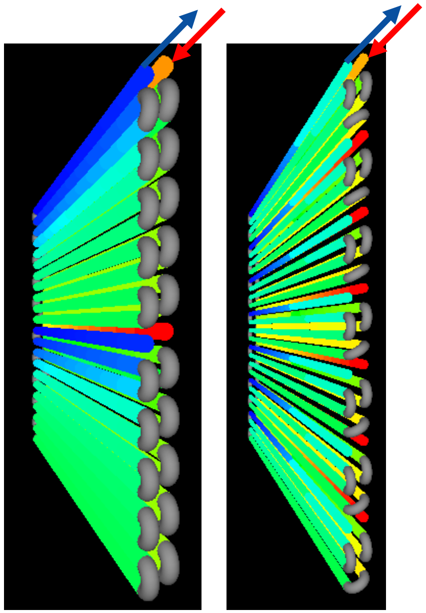


Circuiting

- In order to maintain acceptable refrigerant pressure drops, the mass flux through tubes should not increase significantly
- Baseline has 2 circuits, $mass\ flux, G = \frac{\dot{m}}{A} = \frac{0.02065\ [\frac{kg}{s}]}{2*\frac{\pi}{4}(0.00886\ [m])^2} = \mathbf{167}[\frac{kg}{m^2 * s}]$
- With 5 mm tubes, ID = 4.6 mm;

# Circuits	Mass flux [kg/m²s]
6	207
7	177
8	155





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Air Pressure Drop

- 3-row, 16 FPI design has a 27 Pa pressure drop and improved performance
  - FPI could be reduced further to reduce costs and maintain capacity
- 2-row 24 FPI design has a 37 Pa air-side pressure drop: nearly a 40% increase
  - Consideration of fan curve, may allow for lower FPI design to operate at higher air flow rate and increased capacity
  - We can investigate designs that operate with equivalent fan power ($\propto Q\Delta P$)

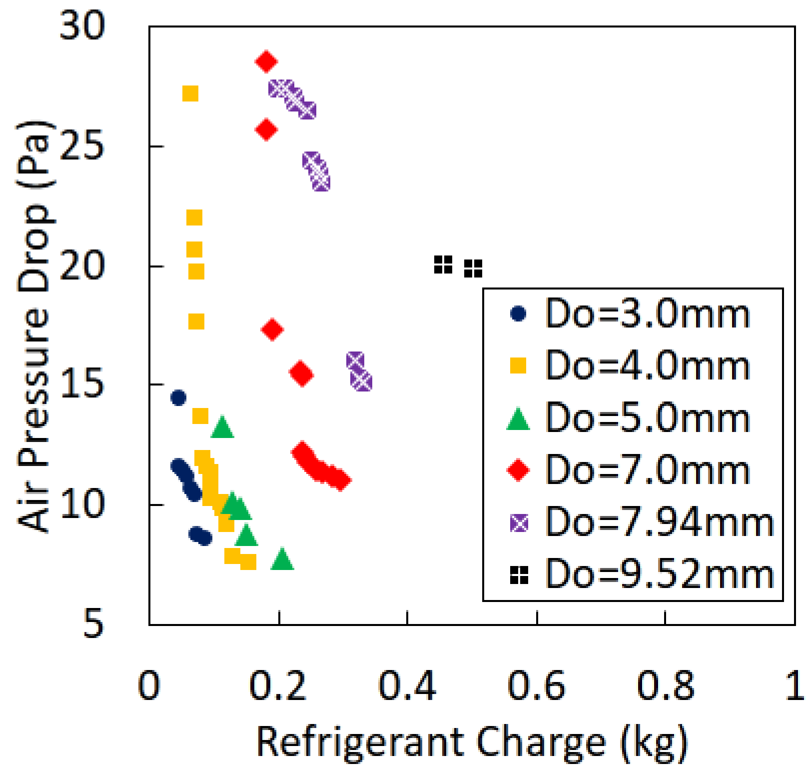
Summary of Candidate Designs

Design	16 FPI – 3 row, 7 circuits	16 FPI – 3 row, 14 circuits	24 FPI – 2 row	17 FPI – 2 row
Air Flow Rate	100%	100%	100%	110%
Air ΔP	100%	100%	135%	83%
Fan Power	101%	101%	135%	91%
Capacity	102%	100%	99%	97%
Refrigerant Pressure Drop	139%	23%	114%	118%
Tube Material	61%	61%	40%	40%
Fin Material	86%	86%	90%	61%
Apprx. Tube Internal Volume	52%	52%	34%	34%

Heat Exchanger Optimization

Optimization Variables	
Parameter	**Value**
P_l	$2xD_o$ to $4xD_o$
P_t	$1.1xP_l$ to $2xP_l$
N_B	1 to 6
FPI	14 to 40
S_h/L_p	$0.3xF_p$ to $0.7xF_p$/0.8 to 1.8 mm
# Tube banks	1 to 5
# Tubes per bank	16 to 32
# Circuits	All numbers evenly divisible by the number of tubes per bank
N_{slits} / $N_{louvers}$	2 to 6 / 2 to 8

Optimization Constraints	
Parameter	**Value**
$T_{in, ref}$	66.0°C / 150.8°F
$P_{in, ref}$	2726.8 kPa / 27.3 bar
$\dot{m}_{ref}$	20.1 g/s / 2.7 lbm/min
$T_{in, air}$	35°C / 95°F
$P_{in,}$ air	101.3 kPa / 14.7 PSI
Air Flow Rate	0.5 m^3/s / 1059.4 CFM
Face Area	0.4 m^2 / 4.3 ft^2
HX aspect ratio (Tube length/height)	<1.5
Subcooling	≥6°C / 10.8°F
Heat load	≥4 kW / 1.14 tons



Summary

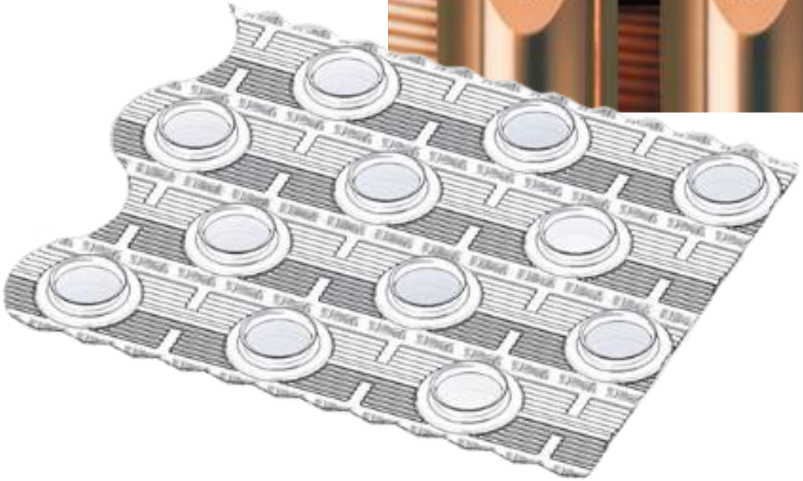
5 mm HX: A Closer Look

Microgroove™ tube:

- Less material consumption
- Internally-enhanced → increased refrigerant heat transfer
- Smaller diameter → increased air-side heat transfer

External fins:

- Customizable, with complex enhancements
- Higher fin densities
- Higher heat transfer



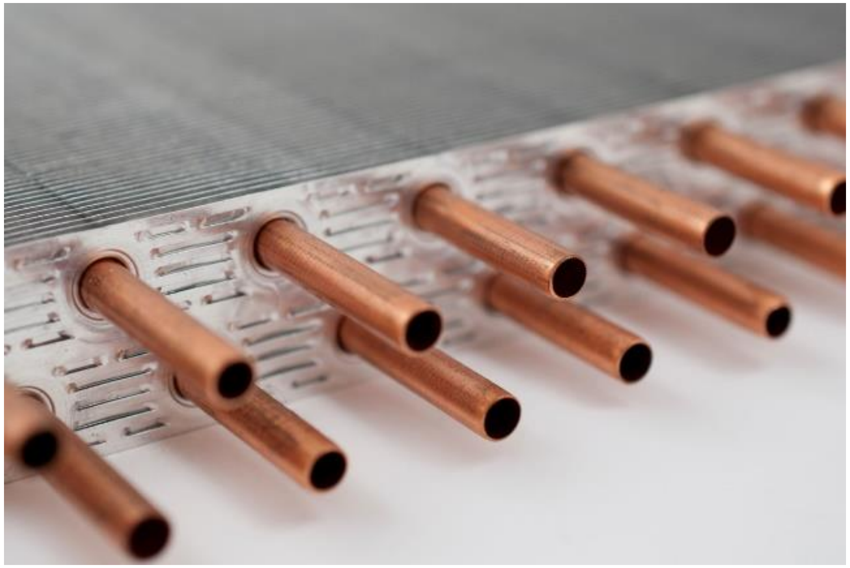
5 mm HX: Putting It All Together

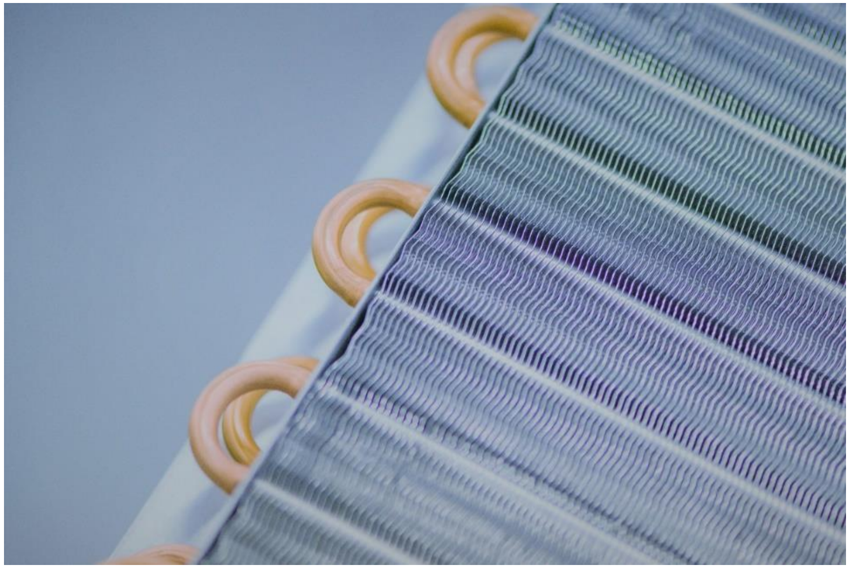
Manufacturing:

- Tube expansion with mechanical or pressure expansion
- Equipment available for tube insertion and fin stacking

Design:

- Select fin and tube arrangement for acceptable air pressure drop
- Design number of circuits to maintain refrigerant pressure drop
- Utilize simulation and optimization tools to maximize performance





Next Steps

- Provide your feedback! Complete the webinar surveys
- Q&A summary sheet to be provided with webinar download materials
- Don't forget to download a copy of the CoilDesigner® demo
- Want a sample heat exchanger?
  - Complete surveys for all three webinars
  - Examine, measure, test, share results

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Thank you

Q&A