12th IEA HEAT PUMP CONFERENCE 2017 | ROTTERDAM

12th IEA Heat Pump Conference 2017

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"Advanced round-tube, plate-fin (RTPF) heat-exchanger coils contribute to the high efficiency of heat pumps"

Nigel Cotton, International Copper Association
Yoram Shabtay, Heat Transfer Technologies LLC

Content

- Overview / Historical trends
- Examples on how small diameter copper tube HX can:
  - Increase the system energy efficiency (COP)
  - Reduce the refrigerant charge
  - Lower HX cost and reduce HX size
- Applications
- Simulation and Design
- Construction and manufacturing
- Where to get more information

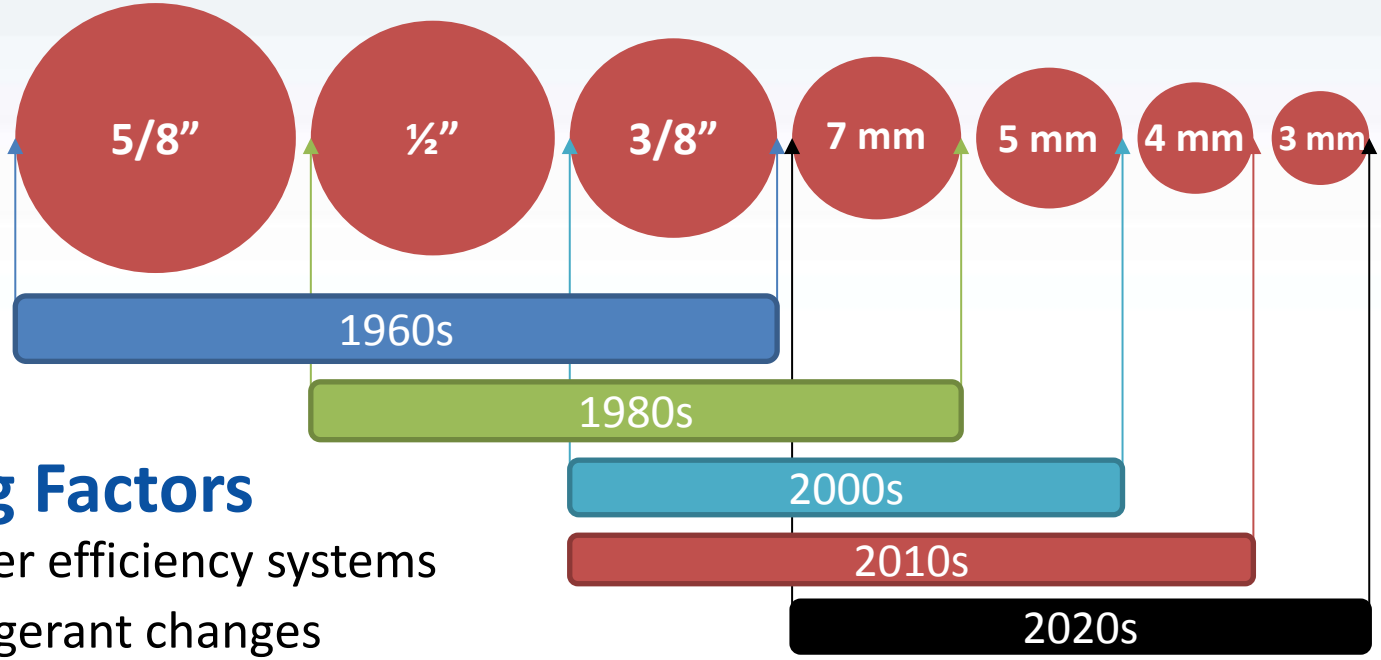
Overview

Smaller-diameter, inner-grooved copper tubes are used in a myriad of products. (Courtesy of Spirotech)

Overview

Areas of Change

- Pattern & Tube Geometry
  - Smaller Tube Diameter and Denser Tube Patterns
  - Reduction in Tube Wall Thickness
- Fin Design & Material
  - Reduction in Fin Thickness
  - Alternate Fin Alloys



Driving Factors

- Higher efficiency systems
- Refrigerant changes
- Material & Labor Costs

Overview

Heat pump applications include:

- Refrigerant-to-air heat exchangers: Outdoor evaporators, indoor condensers, gas coolers, clothes dryers.
- Refrigerant to water heat exchangers: On demand hot water heat pumps, hydronic heating.

Examples:

Condenser coil
254 x 330mm
10” x 13”

CO_2 gas cooler
457 x 940mm
18” x 37”

Example: R290 condenser [19]

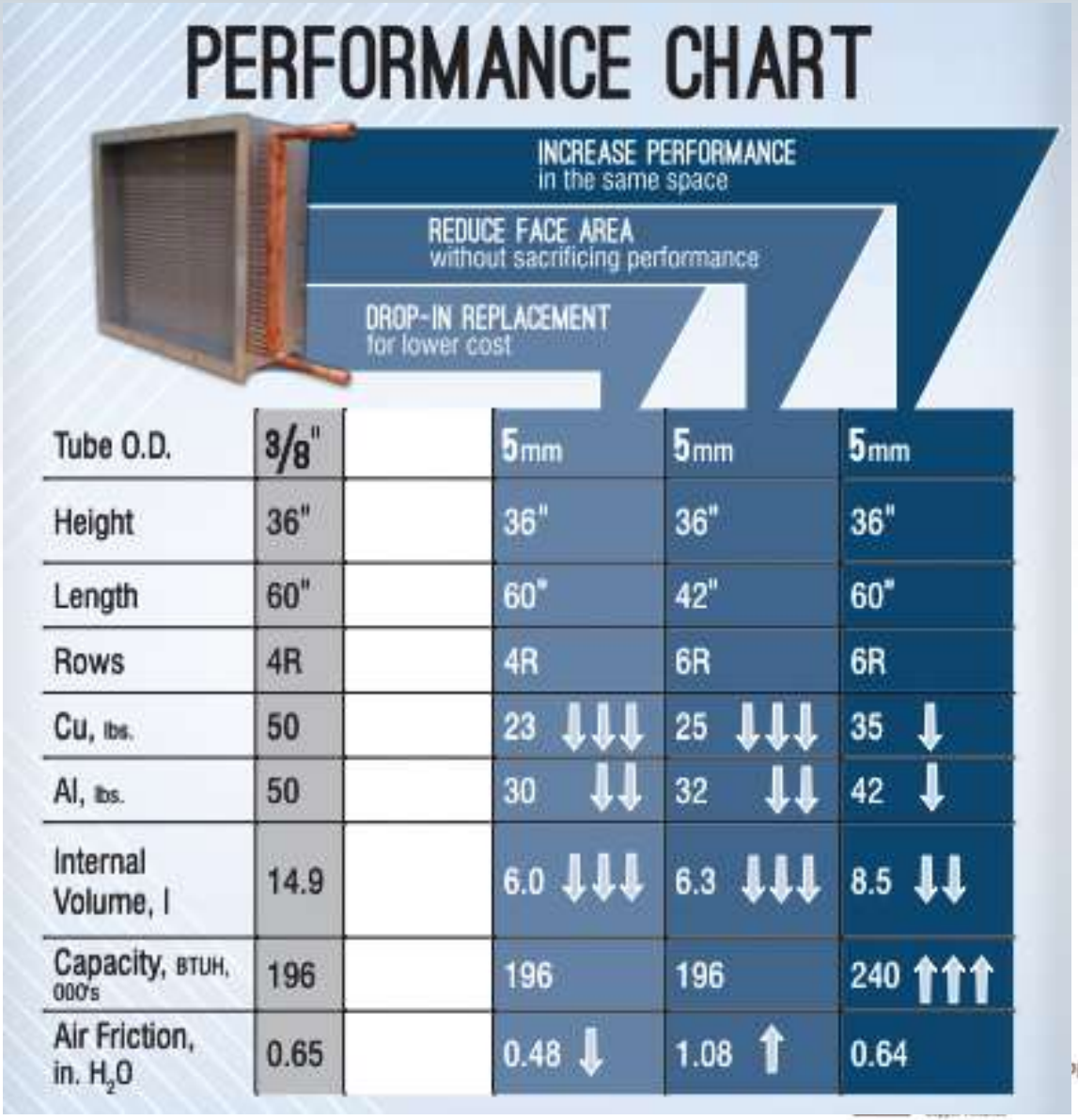
R290 Condenser	Unit	5 mm Tube	3/8” Tube	5/16” Tube
Capacity	BTUH	4715	4426	4477
Design Pressure	PSIA	250	250	250
Coil Size	in	10.5 X 13.25	10x13.25	10x13.25
Row		5	3	4
Fin Density	FPI	8	8	8
Tube Pattern	in	0.75 x 0.449	1.0 x 0.866	1.0x0.625
Tube Material		Cu	Cu	Cu
Tube OD	in	0.197	0.375	0.3125
Tube Wall	in	0.010	0.016	0.013
Tube Weight	**Lbs.**	**2.05 (929g) (82% of 5/16)**	**2.77 (1256g)**	**2.50 (1133g)**
Fin Material		AL	AL	AL
Fin Thickness	in	0.0075	0.0075	0.0075
Fin Weight	**Lbs.**	**1.72 (780g) (97.7% of 5/16)**	**1.82 (825g)**	**1.76 (798g)**
Total Internal Volume	**Liter**	**0.55 (65.5% of 5/16)**	**0.90**	**0.84**

Example: R744 gas cooler

CO2 Gas Cooler	Unit	5mm tube	5/16” tube	Ratio
Capacity	BTUH	43,000	43,000	
Design Pressure	PSIA	1,005	1,005	
Coil Size	in	18 x 37	18 x 37	
Row		4	4	
Fin Density	FPI	16	12.5	
Tube Pattern	in	0.75 x 0.449	1.0 x 0.625	
Tube Material		Cu	Cu	
Tube OD	in	0.197	0.3125	
Tube Wall	in	0.040	0.049	
Tube Weight	**Lbs.**	**24.5 (11.1kg)**	**37.7 (17.1kg)**	**65%**
Fin Material		AL	AL	
Fin Thickness	in	0.0039	0.0045	
Fin Weight	**Lbs.**	**7.5 (3.4kg)**	**9.5 (4.3kg)**	**79%**
Total Internal Volume	**Liter**	**1.2**	**2.2**	**54.5%**

Example: Comparison

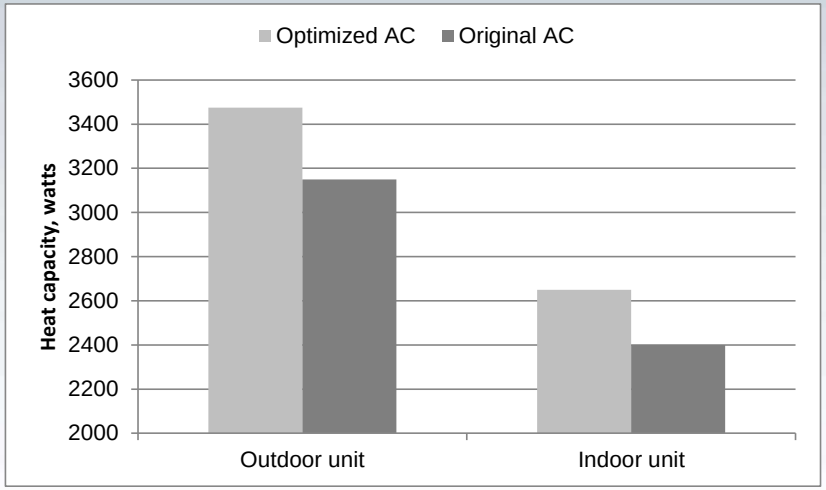
- For R32, R290 and R744 – Smaller diameter copper tube an advantage:



Tube O.D.	3/8"		5mm	5mm	5mm
Height	36"		36"	36"	36"
Length	60"		60"	42"	60"
Rows	4R		4R	6R	6R
Cu, lbs.	50		23 ↓↓↓	25 ↓↓↓	35 ↓
Al, lbs.	50		30 ↓↓	32 ↓↓	42 ↓
Internal Volume, l	14.9		6.0 ↓↓↓	6.3 ↓↓↓	8.5 ↓↓
Capacity, BTUH, 000's	196		196	196	240 ↑↑↑
Air Friction, in. H_2O	0.65		0.48 ↓	1.08 ↑	0.64

Example: R290 for mini-splits

- 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



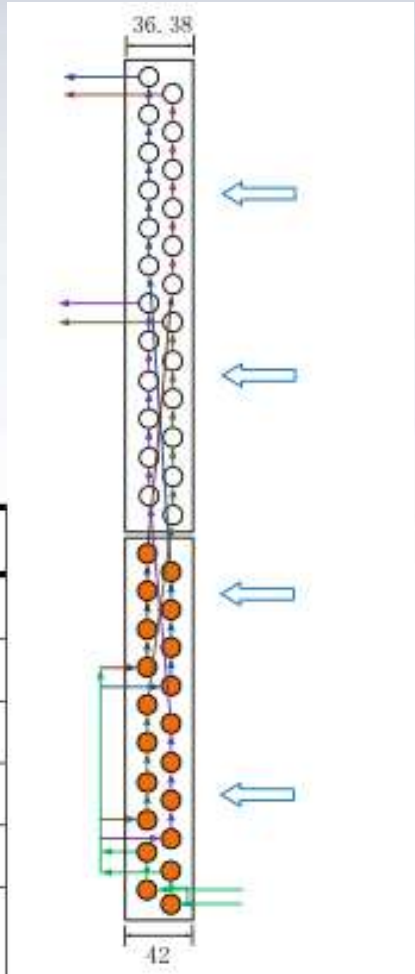
	Original Design	Optimized Design
Refrigerant charge, gm	390	250
Cooling capacity, watts	2,600	2,537
EER, w/w	3.05	3.20
Heating capacity	2,757	2,786
COP, w/w	3.42	3.44
Indoor Unit Heat Capacity, watts	2,403	2,625
Outdoor Unit Heat Capacity, watts	3,183	3,430
Condensing temperature, °C	46.5	44.1
Evaporating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

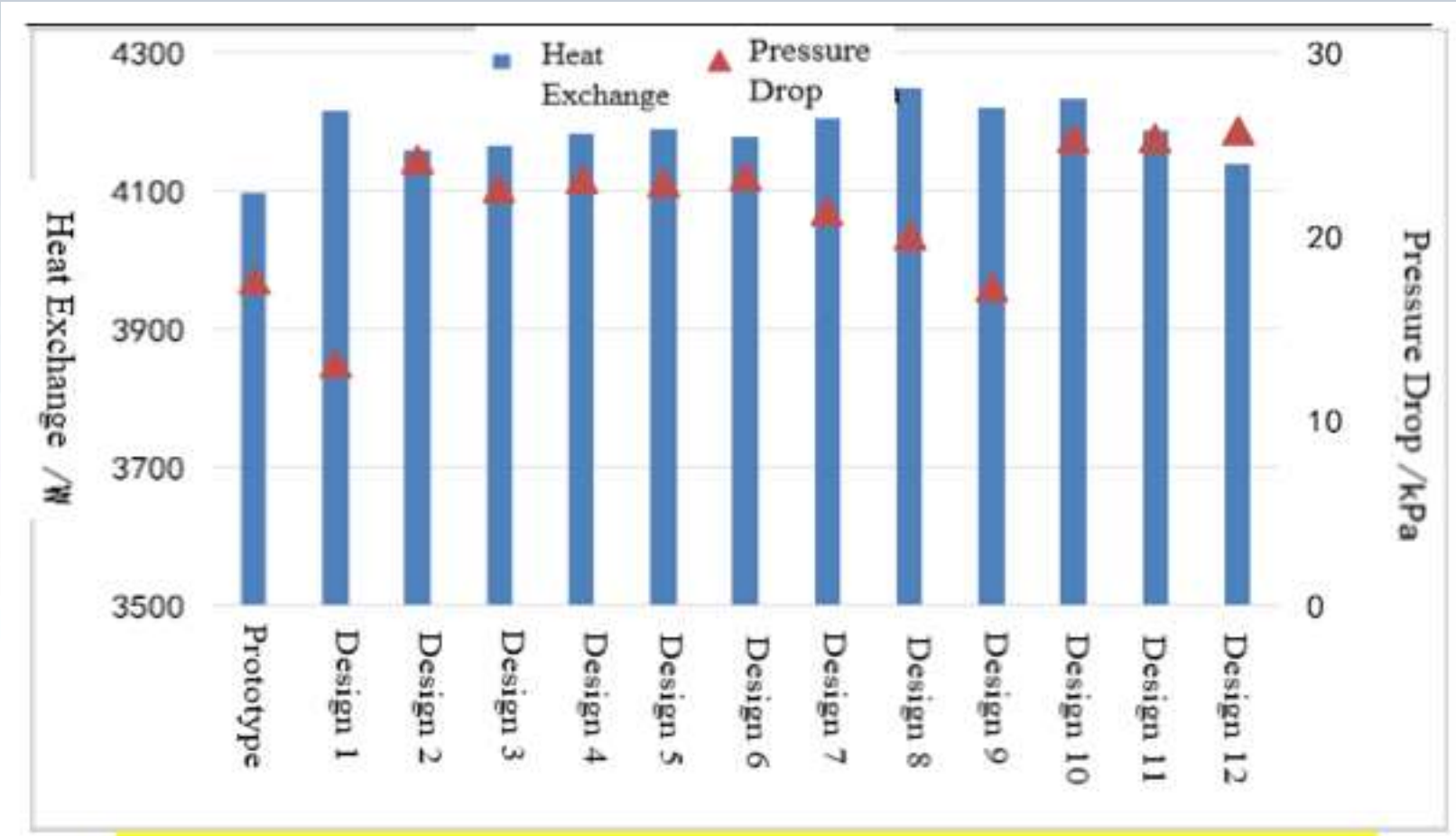
Example: Kelon Mini-split HP

- SJTU simulated the operating performance of 12 Designs
- In Optimization Design 10, SJTU distributed Φ5mm and Φ7mm tubes on different blocks for the convenience of manufacture: the upper block contains 12 Φ7mm tubes and the lower block 10 Φ5mm tubes; the super-cooling section was separated to reduce pressure drop. The lower block shows in orange.

Parameter	Prototype	Design 10	Relative change
Capacity/W	3065.933	3072.003	0.2%
Pressure Drop/kPa	84.071	125.178	41.1
Temperature (outlet)/℃	4.338	4.665	7.5%
Enthalpy (outlet)/(kJ/kg)	425.499	425.879	0.1%
Super-heating Degree/℃	4.202	4.572	0.4
Heat Transfer Coefficient/(W/m² • K)	4696.499	5832.793	24.2%



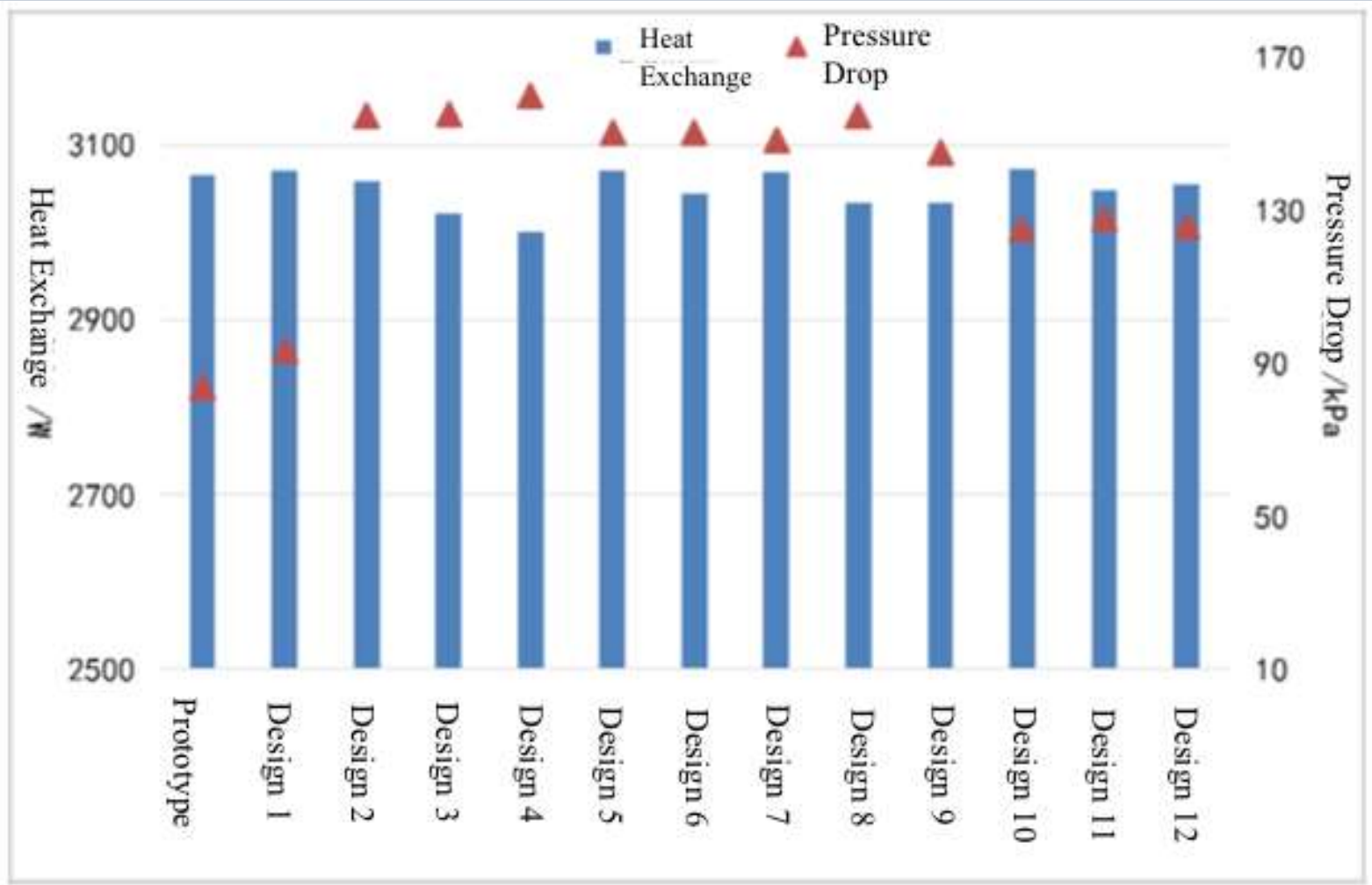
Example: Kelon mini-split HP



Optimization performance summary - Cooling

Design 11 is more suitable for I-type heat exchangers and performs better in cooling condition

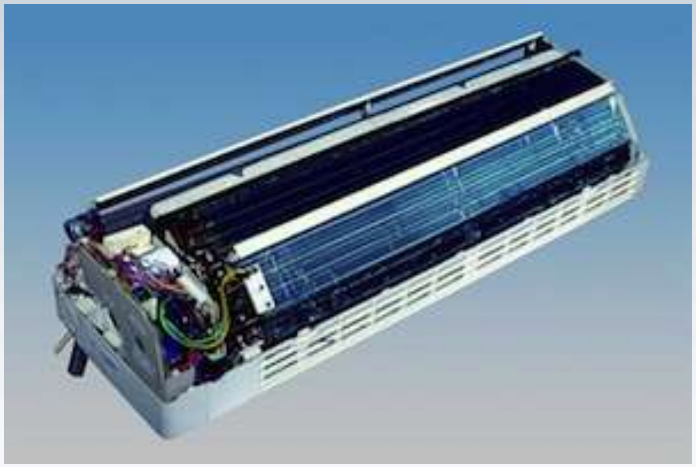
Example: Kelon Mini-split HP



Optimization performance summary - Heating

Design 12 is more suitable for L-type heat exchangers and performs better in heating condition

Example Kelon mini-split HP



Evaporator made from 5 mm copper. Courtesy Kelon.

Example: Window AC condenser

- Improve system performance
- Reduce cost
- Reduce refrigerant charge
- Slit and louver fin designs considered, working with a manufacturing partner

FRIEDRICH

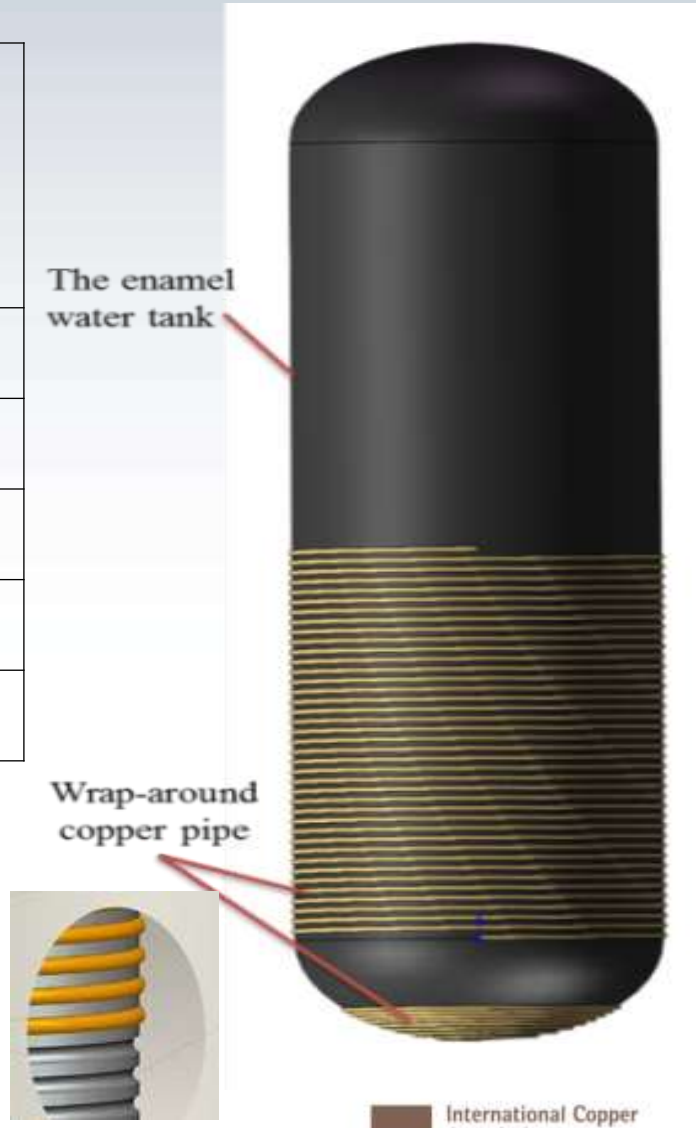
Design	Tube material [kg]	Fin material [kg]	Material Reduction [%]	Simulated Cond. Charge Reduction [%]	Simulated (Measured) COP	COP Improvement [%]
Baseline	1.8	3.2	-	-	2.60 (2.86)	-
Louver fin 17 FPI 4 row	1.5	1.7	**37%**	**21%**	2.77 (2.97)	**6.5% (4.1%)**

Experiment: Louver fin coil achieves 10% *system* charge reduction and 4% COP increase while reducing HX cost by approximately 37%

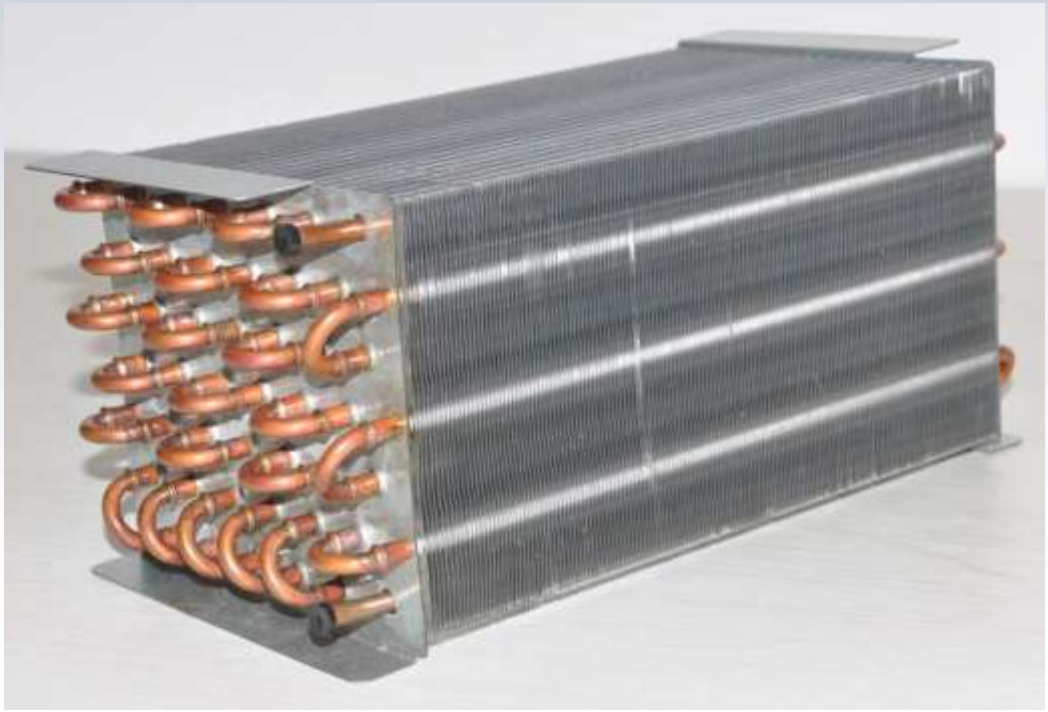
Air Source Heat Pump Water Heater

Tube Diameter (mm)	# of turns	Tube weight (kg)	Heating time (minutes)
9.52	39	9.06	155
7	39	3.33	167
5	39	1.89	179
5	60	2.6	165
5	80	3.28	152

For tube spacing of 10mm, 5mm and 80 turns provides similar heating time to 9.52mm with only **36%** weight.



RTPF-HX Application

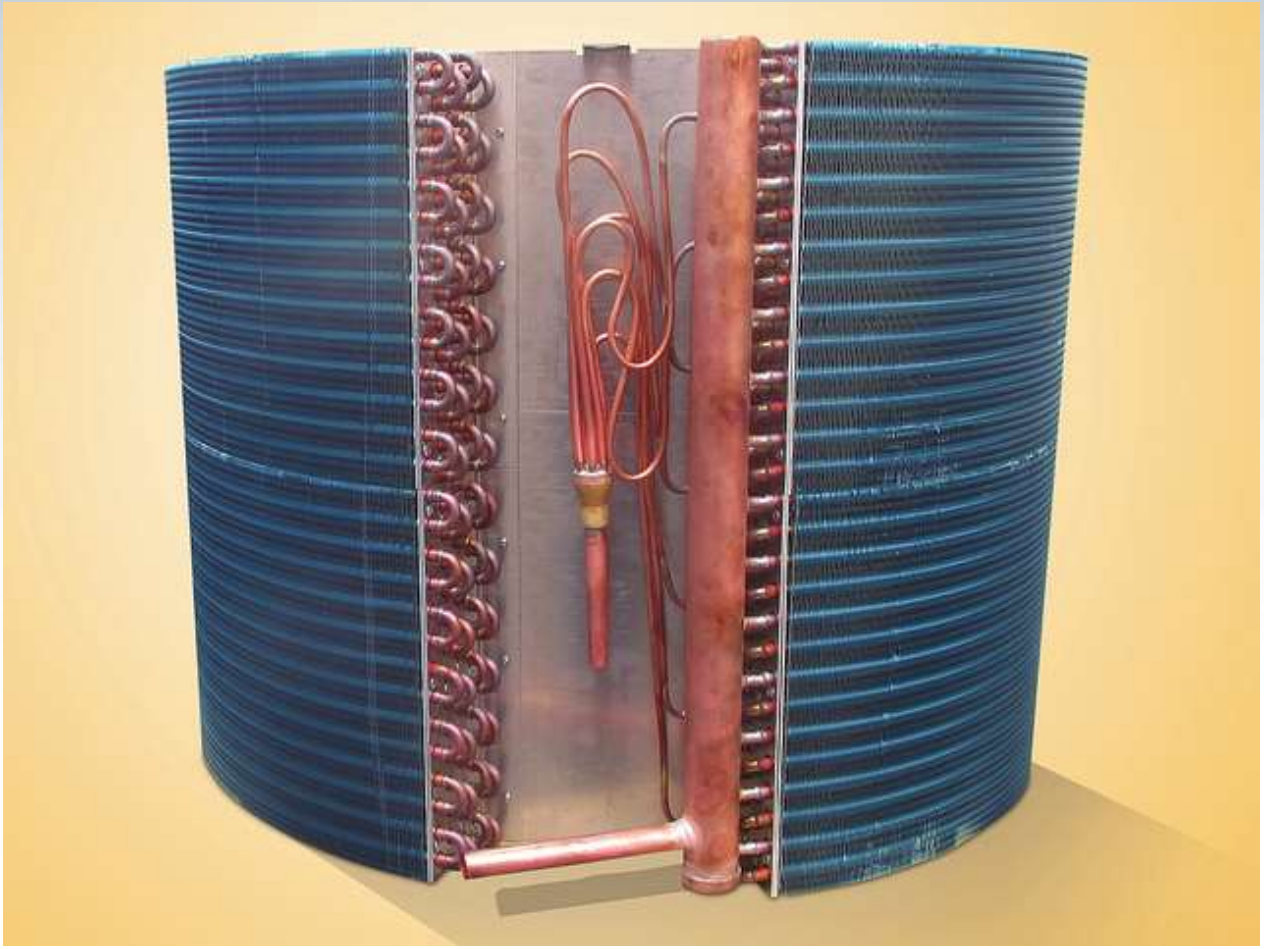


Heat exchanger with 5-mm copper tubes for clothes-drying heat pumps.
(Image Courtesy of Spirotech)

RTPF-HX Application

Condenser with 5-mm copper tubes for split AC .
(Courtesy of Spirotech.)

RTPF-HX Application



Outdoor coil for heat pump with 7 mm copper tubes.
(Courtesy of Lordan)

RTPF-HX Application

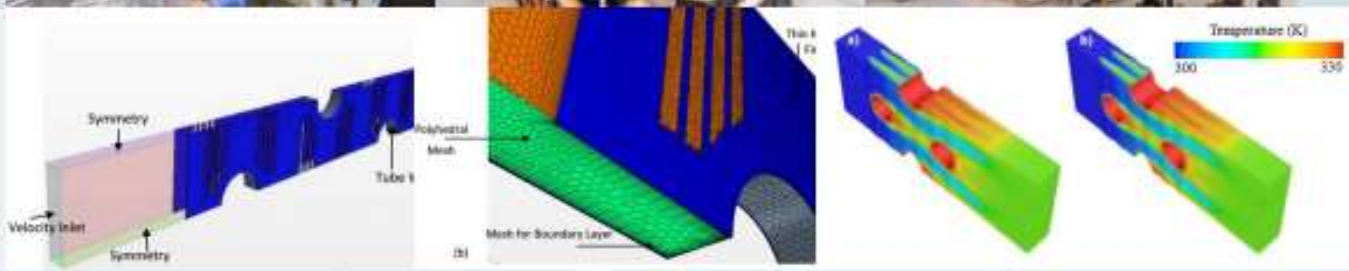
Coil made from 5 mm copper tubes as designed for use in a R744 gas cooler. Courtesy Spirotech.

Computer Simulation

Three methods to design heat exchangers:

Experimental

Numerical (e.g. CFD)

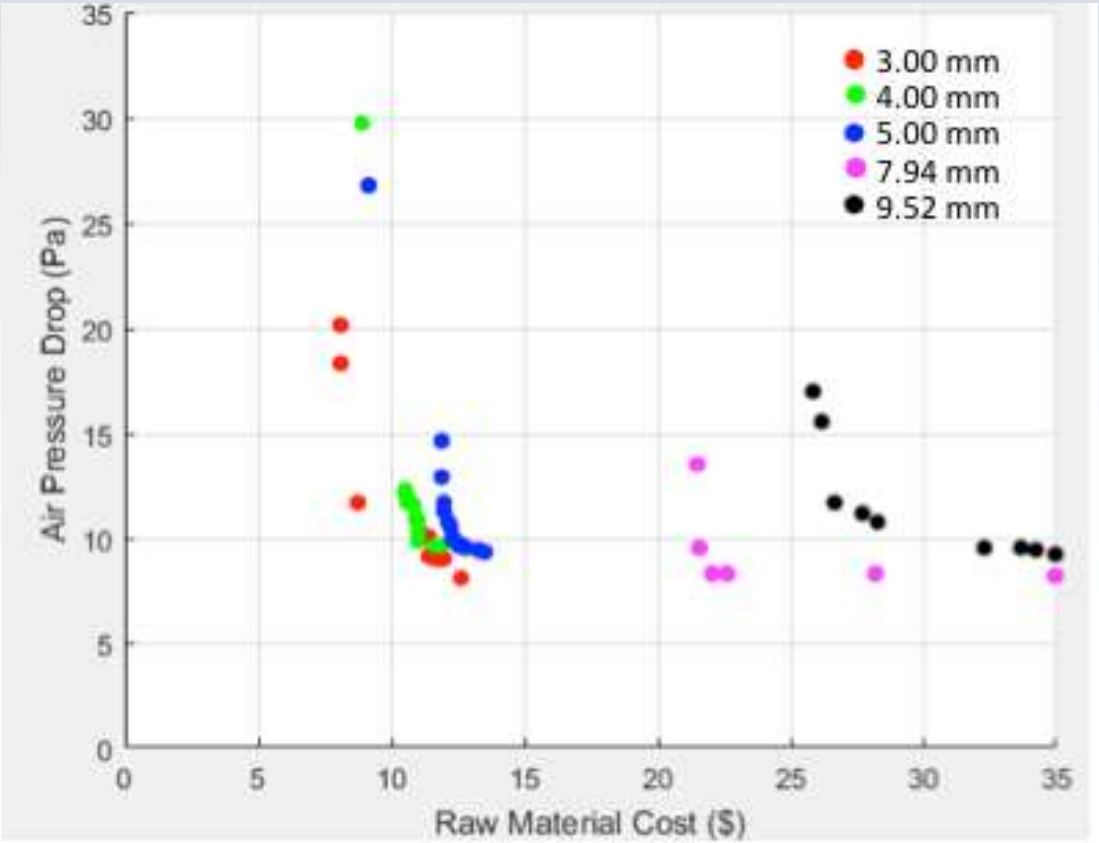


Approximation (correlations)

$$j = c_1 \mathrm{Re}_{D_o}^{B_1} N_t^{B_2} \left(\frac{F_p}{D_o + 2\delta_f}\right)^{B_3} \left(\frac{P_t}{D_o}\right)^{B_4} \left(\frac{P_l}{D_o}\right)^{c_2} \qquad f = c_1 \mathrm{Re}_{D_o}^{B_1} N_t^{B_2} \left(\frac{F_p}{D_o + 2\delta_f}\right)^{B_3} \left(\frac{F_p}{D_o}\right)^{B_4} \left(\frac{F_p}{P_t}\right)^{c_2}$$

Computer Simulation

- Simulation software gives user the option to choose a tube diameter, inner groove tube geometry, fin design and refrigerant type
- Optimizes entire system of compressor, evaporator, and condenser with a cost analysis
- Simulates all key technical parameters needed to optimize the performance and cost of small diameter copper tube heat exchangers and total system



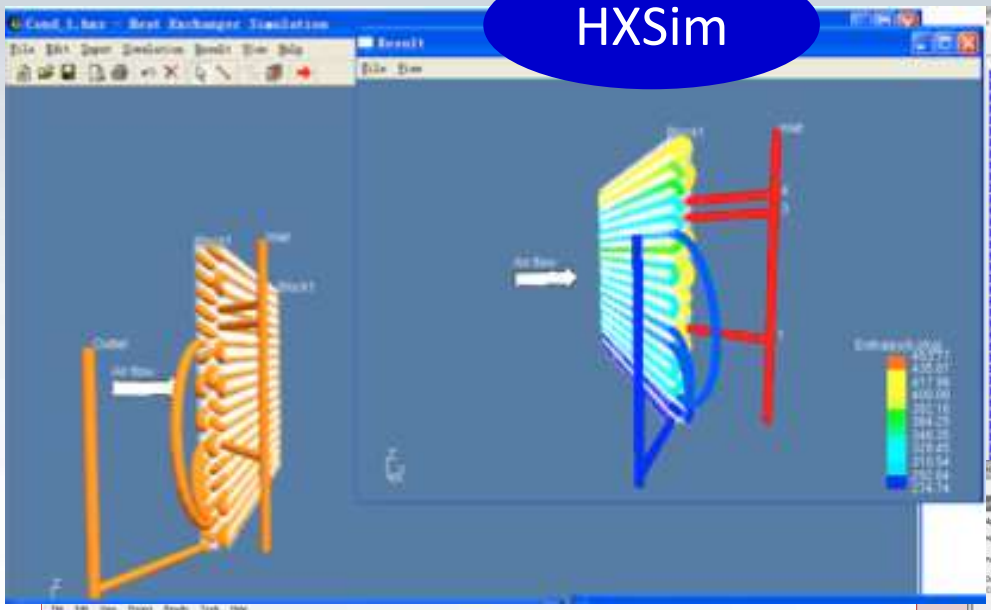
Computer Simulation

Coil designs can be optimized using the following software platforms:

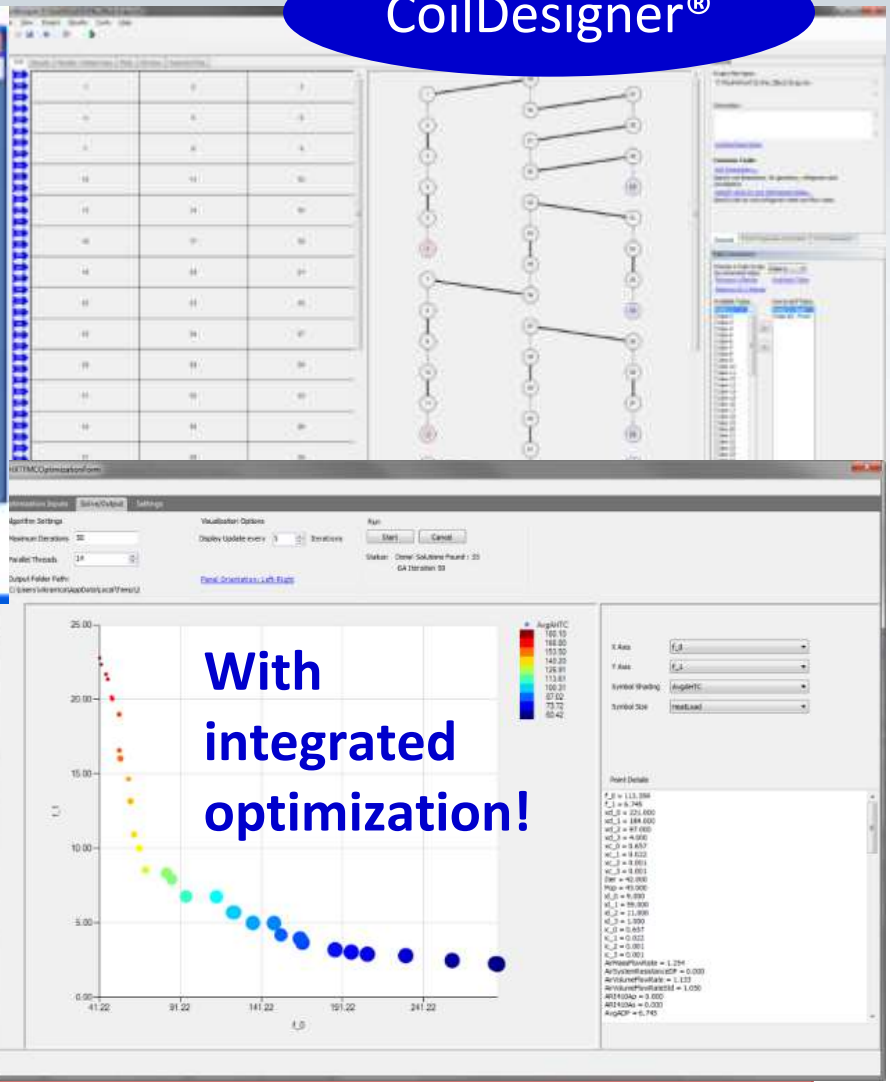
- CoilDesigner® developed at the Center for Environmental Energy Engineering (CEEE) at the University of Maryland and available for use through Optimized Thermal Systems (OTS)
- HEXSIM developed in China through consortium with tube manufacturers, universities and OEMs.
- Internally developed software programs from various coil makers and OEMs.

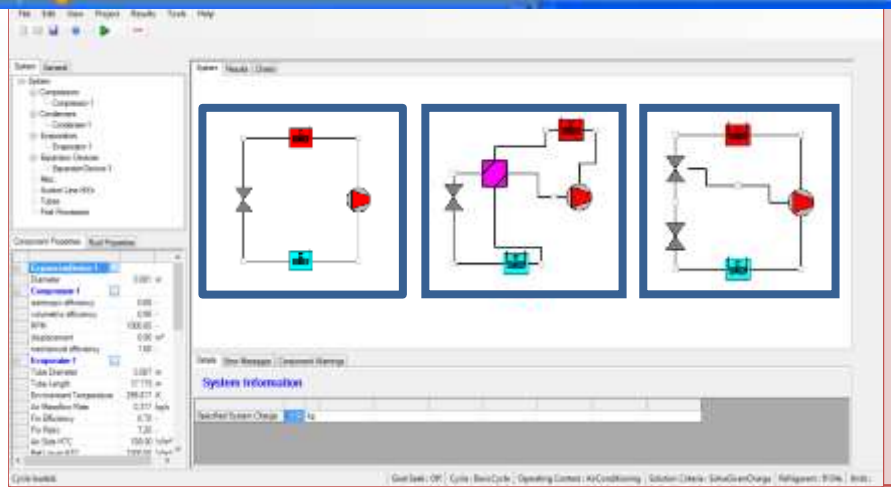
Computer Simulation

HXSim



CoilDesigner®

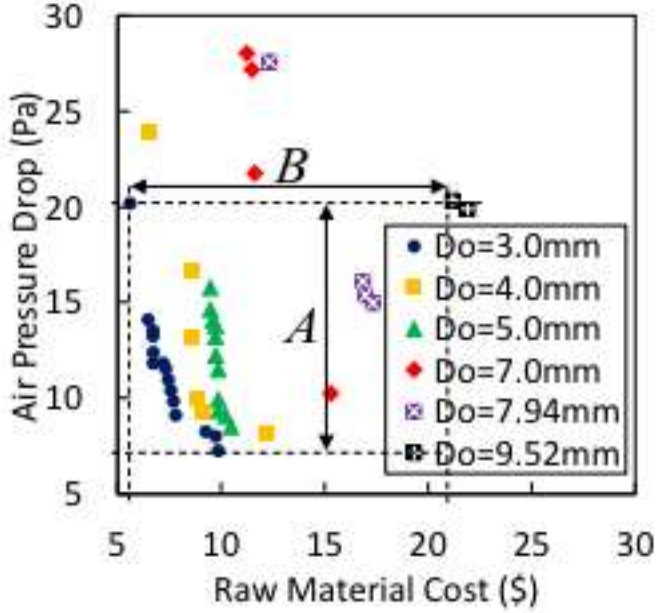


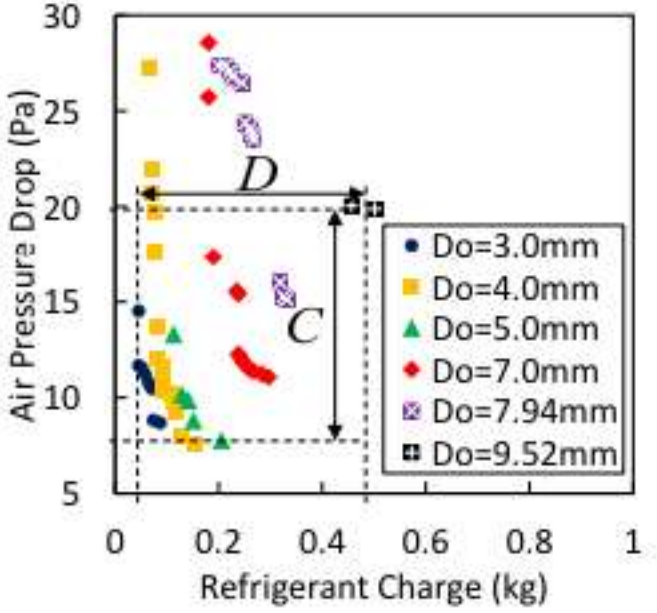


Computer Simulation-Example

Identify optimal drop-in replacement condenser for 1-Ton split AC:

- Constraints:
  - Equivalent performance to baseline
- Objectives:
  - Minimize airside pressure drop,
  - lower material consumption and
  - lower refrigerant charge





Max values:

$A = 64\% \downarrow$

$B = 74\% \downarrow$

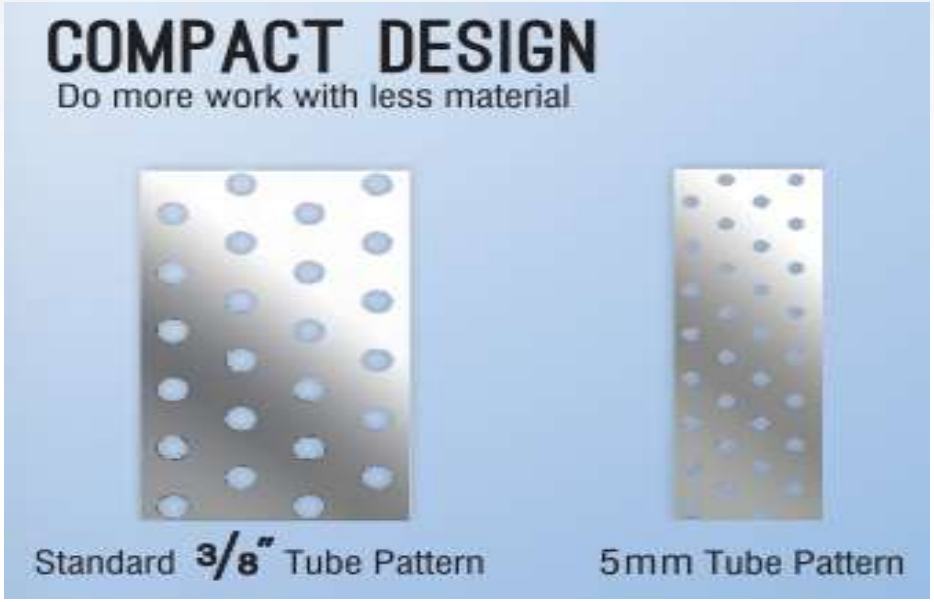
$C = 62\% \downarrow$

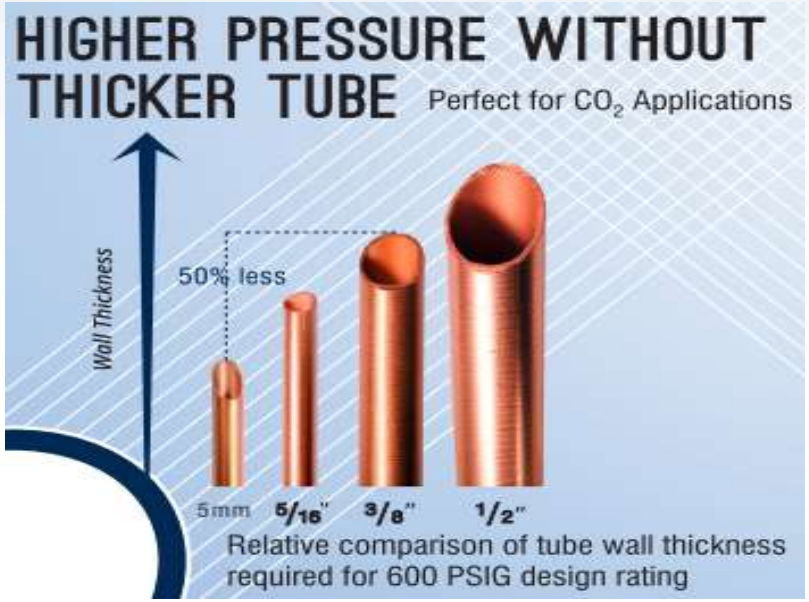
$D = 91\% \downarrow$

ASHRAE 20012 "**Comparative Study of Optimized Small Diameter Tube-Fin Heat Exchangers Vs. Traditional, Larger Diameter Tube-Fin Heat Exchanger Designs" Dennis Nasuta, Shekhar Sarpotdar, PhD. Cara Martin**

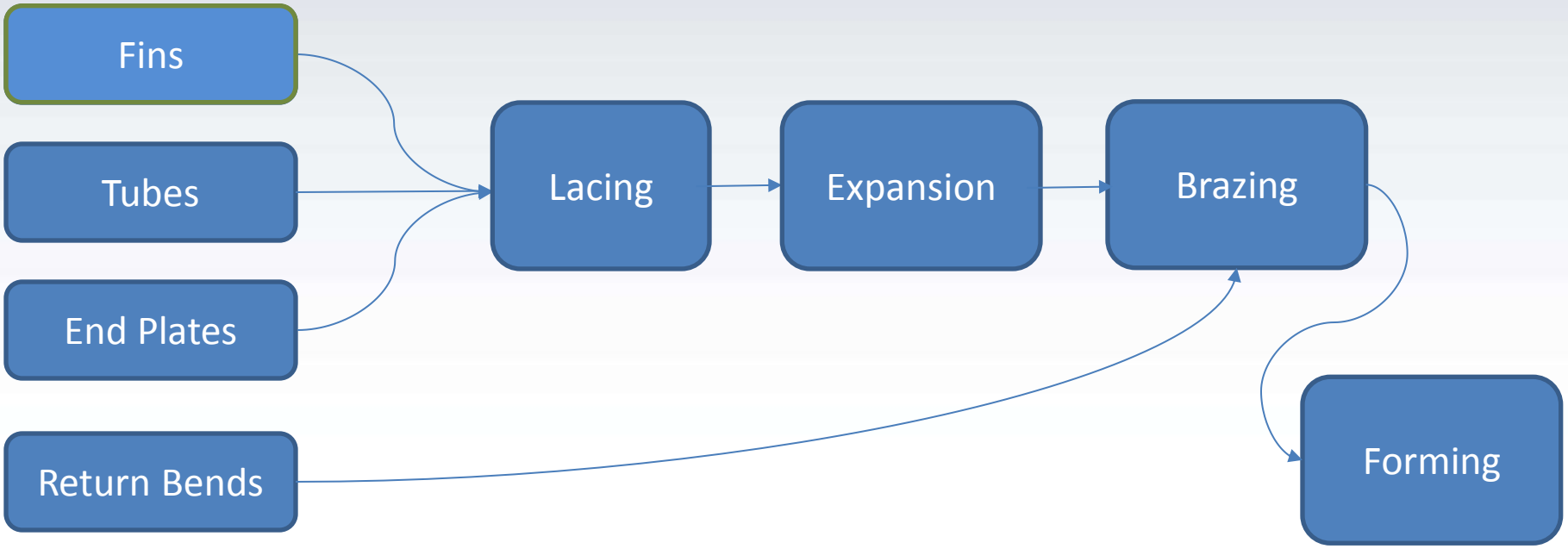
RTPF-HX DESIGN

- Higher pressure capable, Lower refrigerant charge, Compact design
- High-strength copper alloy (CuFe2P) available for even higher pressure

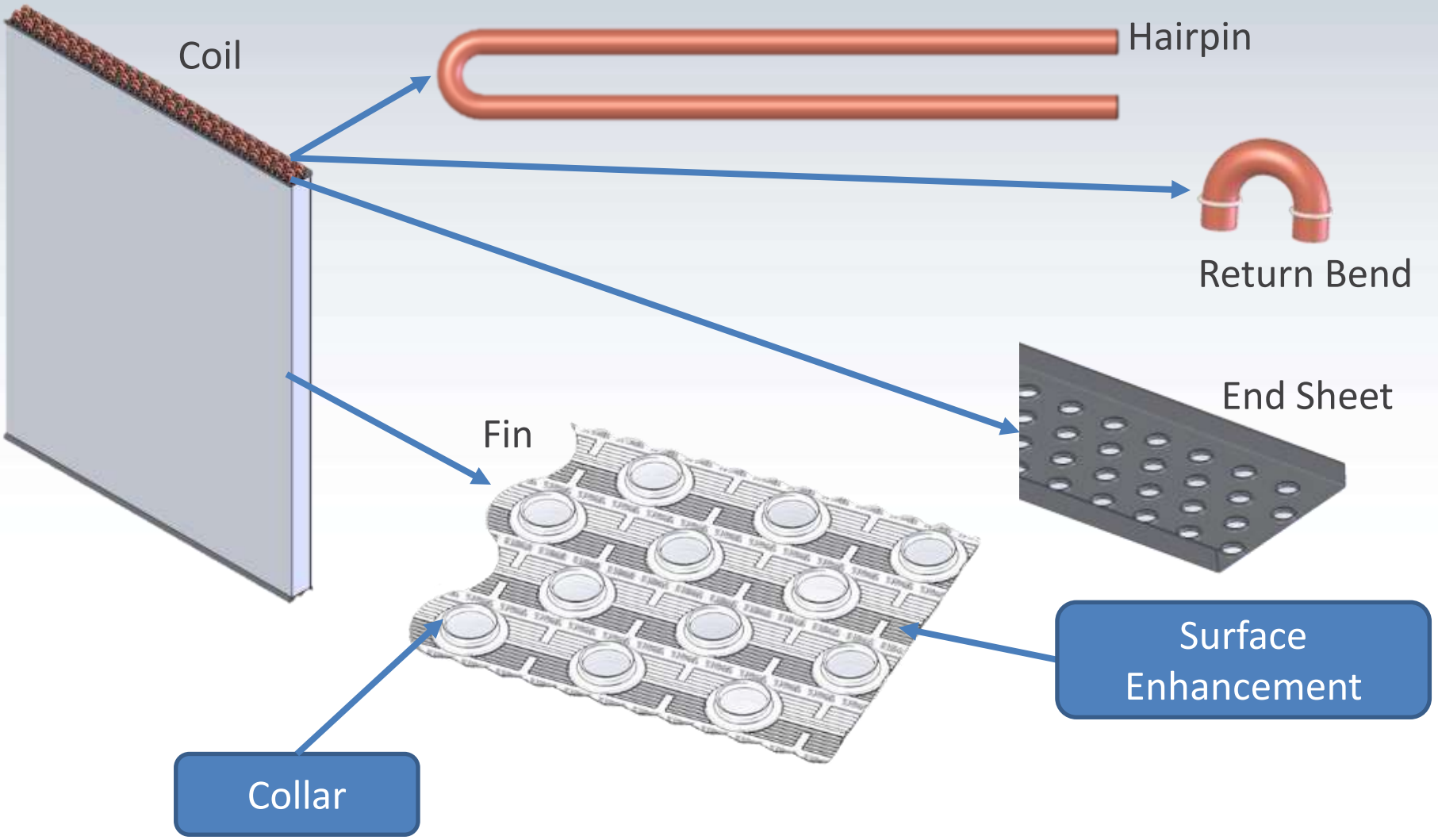




RTPF-HX Construction



RTPF-HX Construction



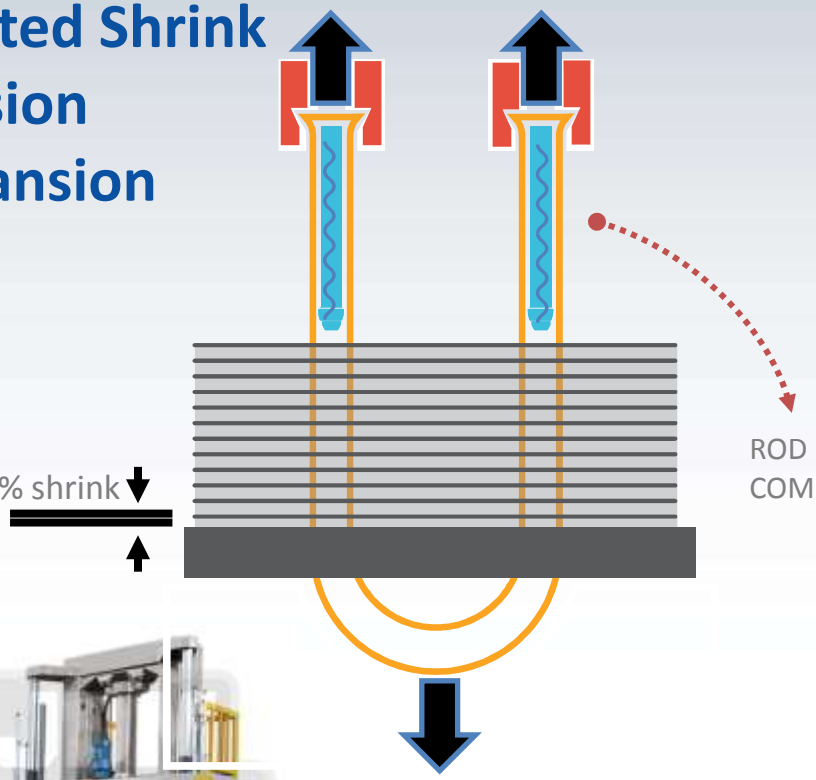
RTPF-HX Construction

The Effects of Using Small Diameter Tubes:

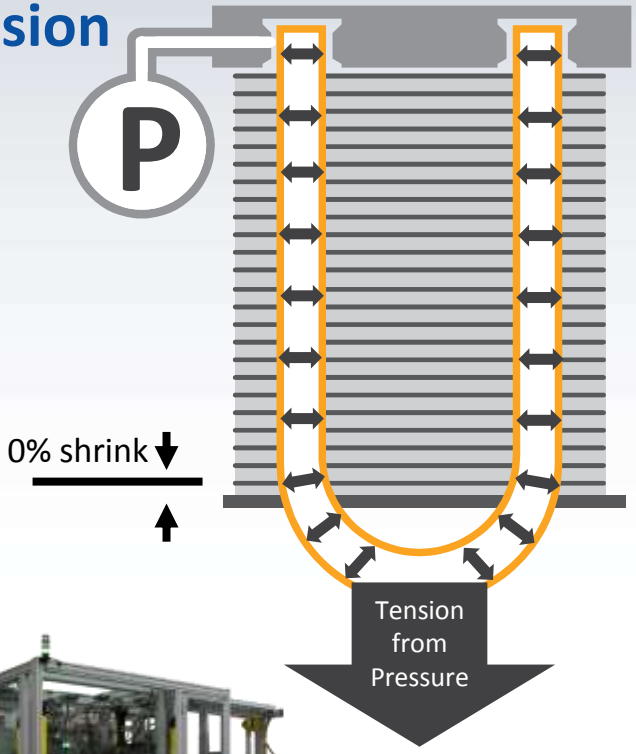
- Higher hoop strength
  - Withstand higher operating pressures
- Reduced wall thickness
  - Reduce material consumption – cost savings!
- Greater fin complexity
  - Both design and density

RTPF-HX Manufacturing

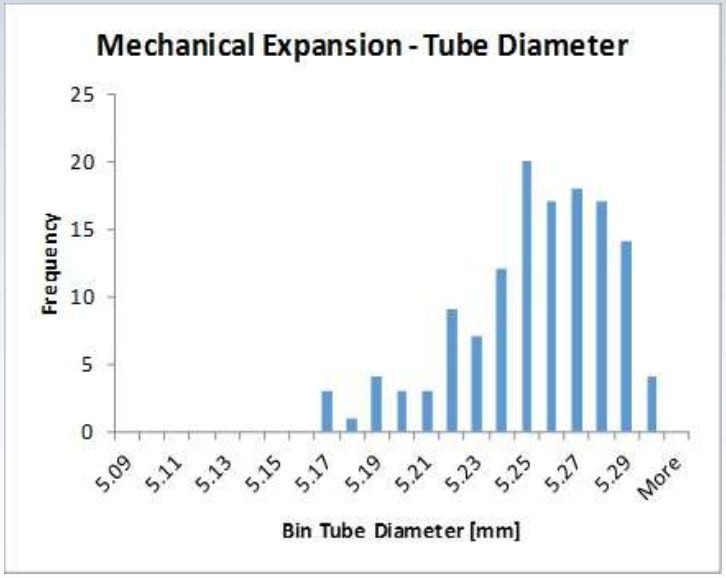
Limited Shrink Tension Expansion



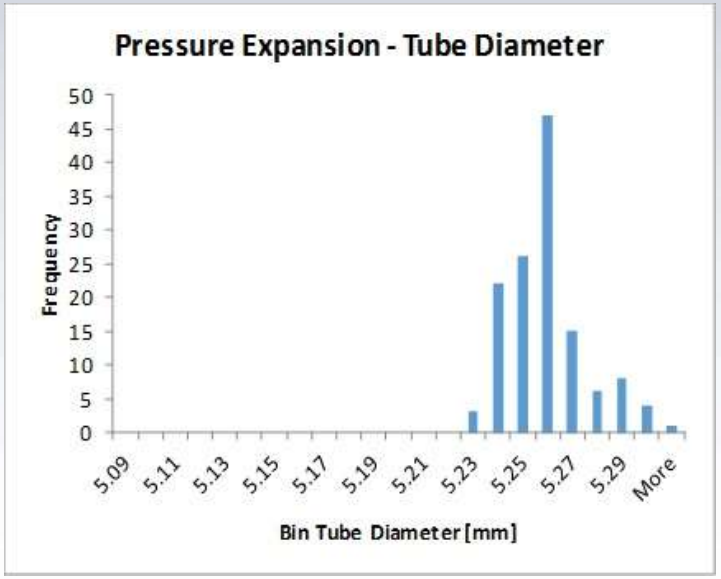
Pressure Expansion



RTPF-HX Manufacturing



S.D. = 0.029 mm



S.D. = 0.016 mm

The pressure expansion resulted in:

- No damage to internal enhancements
- Improved contact between tube and fin

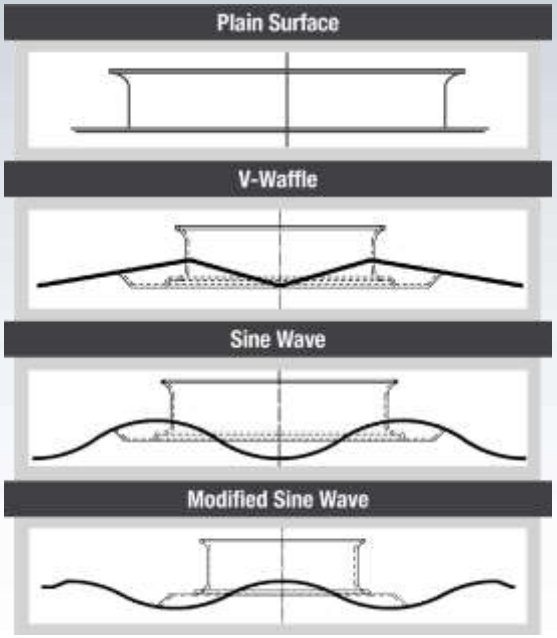
A new white paper is now available from Burr Oak addressing the issue of safety [3]

Drainage

A major advantage of RTPF coils is ease of cleaning and good condensate drainage.

Plate fins are vertically oriented : Water drains top to the bottom .
Tubes penetrate the sheets at right angles: Water easily flows around them.
Wavy Fins are plate fin with no holes: Drain better

Wavy Fins are suitable for:
Outdoor evaporators subject to frosting
Refrigeration equipment



Educational

OTS-ICA Educational Outreach Program:

-Three Webinars
(Archived on MicroGrooveTech YouTube Channel)
-Coil Samples for participants
-Trial version of CoilDesigner for participants
-HXSim software available

www.microgroove.net/ots-ica-educational-outreach

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Small Tube Copper Is Economical and Eco-Friendly

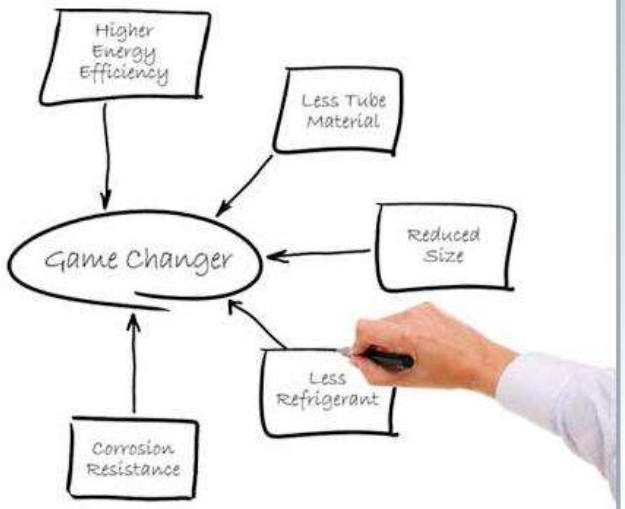
It packs all the advantages of copper into more compact, more efficient heat exchanger coils, reducing the cost of high efficiency air conditioners and refrigerators.

Using proven, cost effective copper fabrication processes and familiar assembly techniques, suppliers and manufacturers are already producing new commercial and residential air conditioning and refrigeration products based on small diameter MicroGroove copper tubing.

Please see "Overview" and "Technical Materials" to learn more about

- Cost-effective fabrication and assembly
- Smaller size, less weight and lower material costs
- Higher heat transfer coefficients
- Well suited for new refrigerants
- Uses less refrigerant
- Overall reduction in system cost

www.microgroove.net



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