2018 Purdue Conferences
Compressor Engineering
Refrigeration and Air Conditioning
High Performance Buildings

Optimization of MicroGroove Copper Tube Coil Designs for Flammable Refrigerants

July 11 -14, 2018

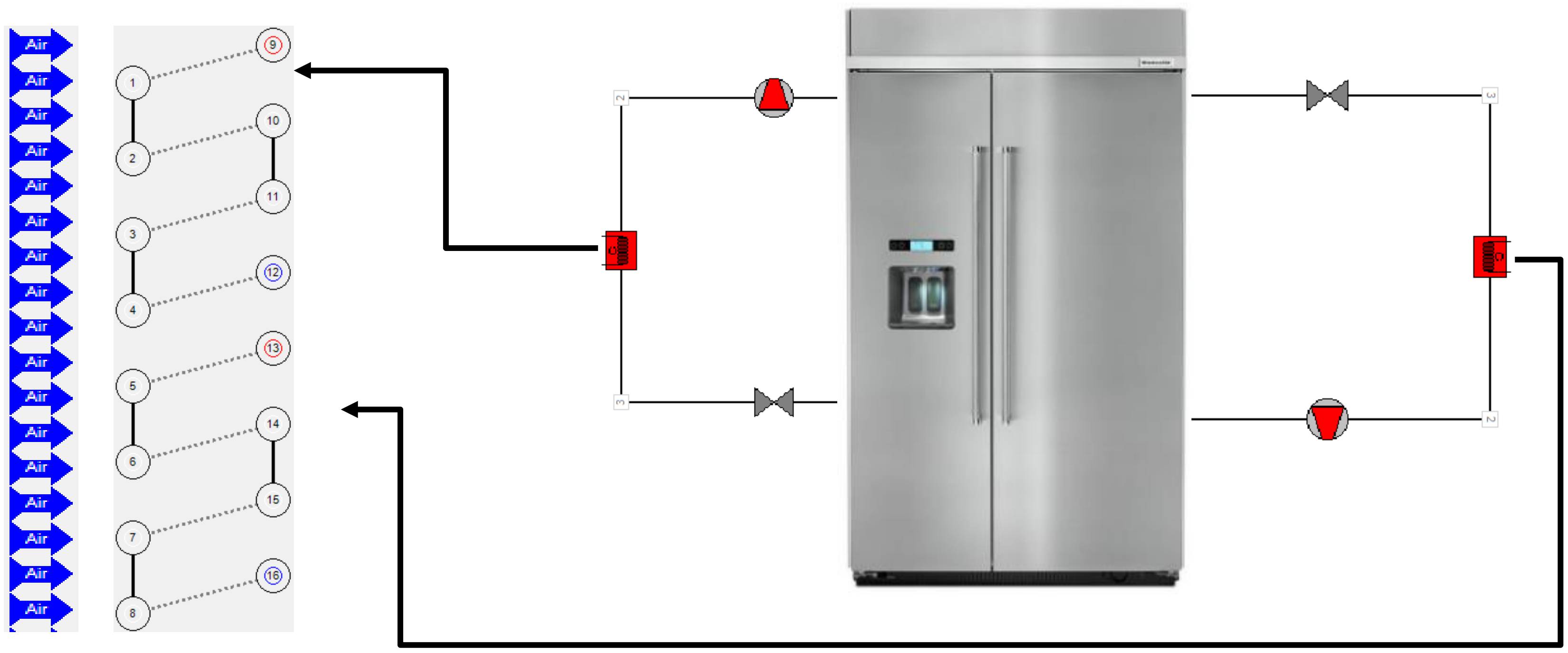
Simulation of Isobutane Condensers

- Baseline condenser coil
  - » 6.35 mm (1/4”) O.D. copper tubing with wavy fins and R134a.
- Main Motivation:
  - » Max. 57g charge of Natural Refrigerant R600a while maintaining performance for condenser in domestic refrigerator application

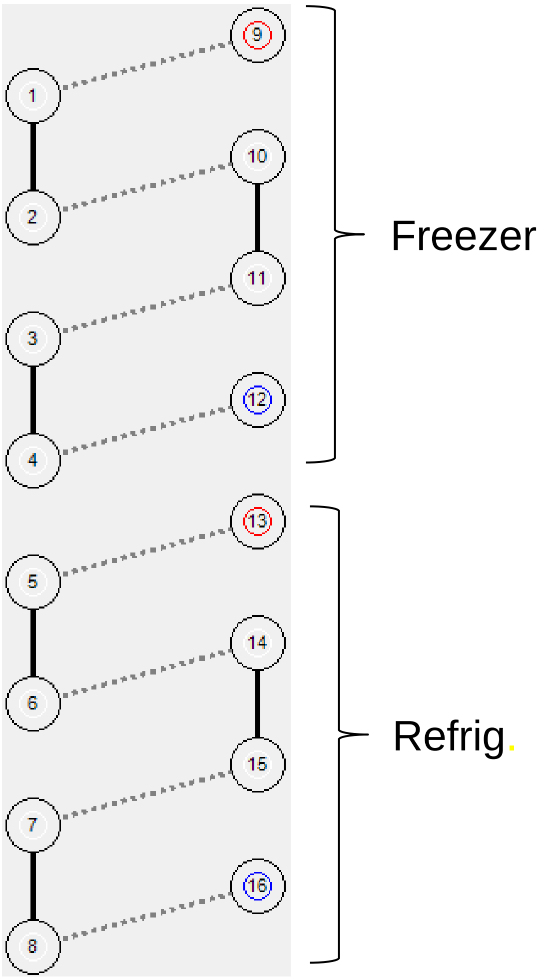
Baseline System

The baseline refrigerator uses two vapor compression cycles (VCCs) which share a condenser to maintain the freezer and refrigerator temperatures

The condenser coil has two circuits, each circuit serves one of the VCCs



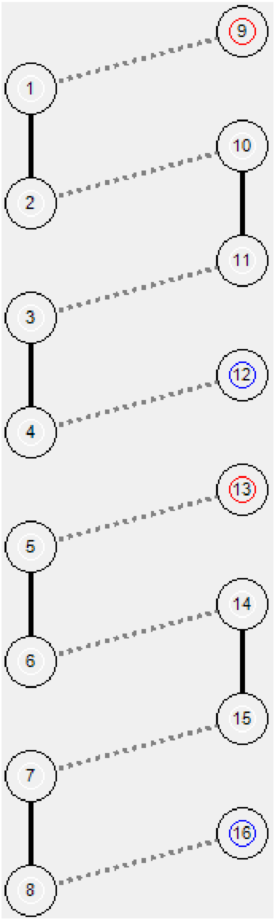
Baseline Condenser



Tube Diameter (mm)	6.5
Tubes per Bank	8
Tube Banks	2
Horizontal Spacing (mm)	22.75
Horizontal Spacing / Outer Diameter	3.5
Vertical Spacing (mm)	26
Vertical Spacing / Outer Diameter	4.0
Tube Length (mm)	432
Fin Type	Flat
FPI	7
Fin Thickness (mm)	0.19

5mm Circuit Design 1

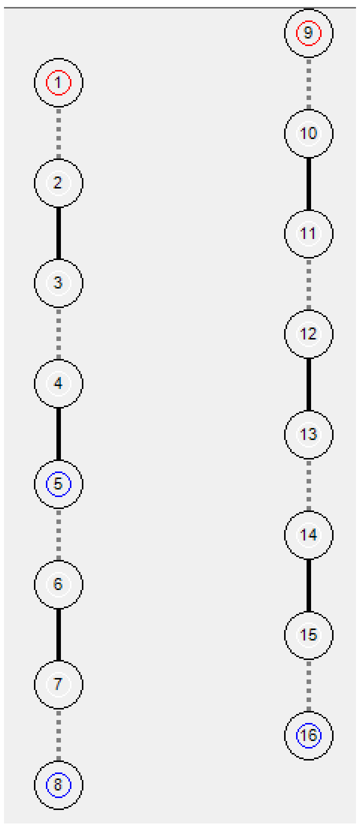
Design 1 keeps the circuit design of the baseline while reducing the tube diameter to 5mm, increasing the FPI to 10



	Baseline Dimension	New Dimension
Tube Diameter (mm)	6.5	5
Tubes per Bank	8	8
Tube Banks	2	2
Horizontal Spacing (mm)	22.75	17.5
Horizontal Spacing / Outer Diameter	3.5	3.5
Vertical Spacing (mm)	26	20
Vertical Spacing / Outer Diameter	4.0	4.0
Tube Length (mm)	432	432
Fin Type	Flat	Flat
FPI	7	10
Fin Thickness (mm)	0.19	0.14

5mm Circuit Design 2

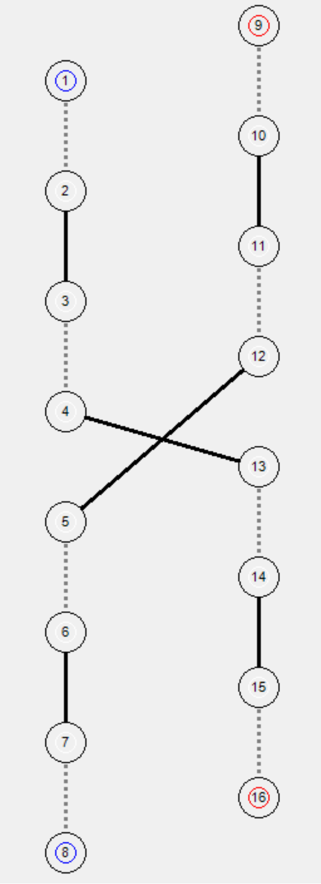
Design 2 uses the geometry changes of Design 1, moves one of the circuits behind the other (in the airflow direction) and straightens out the circuits to keep the same tube pattern as the baseline



	Baseline Dimension	New Dimension
Tube Diameter (mm)	6.5	5
Tubes per Bank	8	8
Tube Banks	2	2
Horizontal Spacing (mm)	22.75	17.5
Horizontal Spacing / Outer Diameter	3.5	3.5
Vertical Spacing (mm)	26	20
Vertical Spacing / Outer Diameter	4.0	4.0
Tube Length (mm)	432	432
Fin Type	Flat	Flat
FPI	7	10
Fin Thickness (mm)	0.19	0.14

5mm Circuit Design 3

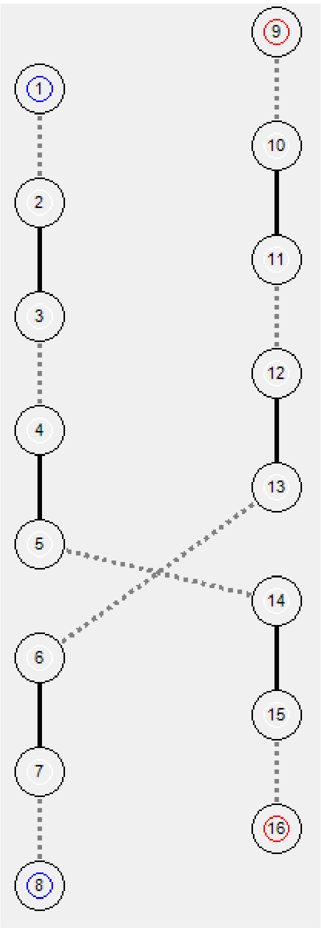
Design 3 is similar to Design 2 but has half of each circuit first in the airflow direction, half second



	Baseline Dimension	New Dimension
Tube Diameter (mm)	6.5	5
Tubes per Bank	8	8
Tube Banks	2	2
Horizontal Spacing (mm)	22.75	17.5
Horizontal Spacing / Outer Diameter	3.5	3.5
Vertical Spacing (mm)	26	20
Vertical Spacing / Outer Diameter	4.0	4.0
Tube Length (mm)	432	432
Fin Type	Flat	Flat
FPI	7	10
Fin Thickness (mm)	0.19	0.14

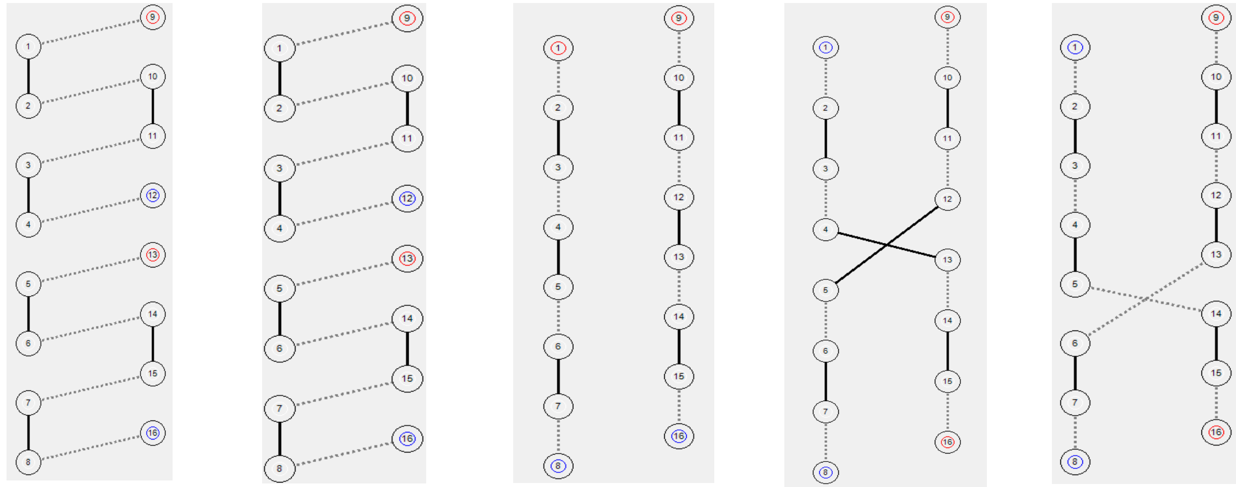
5mm Circuit Design 4

Design 4 is similar to Design 3 but splits the front-back divide into 5-3 instead of an even 4-4



	Baseline Dimension	New Dimension
Tube Diameter (mm)	6.5	5
Tubes per Bank	8	8
Tube Banks	2	2
Horizontal Spacing (mm)	22.75	17.5
Horizontal Spacing / Outer Diameter	3.5	3.5
Vertical Spacing (mm)	26	20
Vertical Spacing / Outer Diameter	4.0	4.0
Tube Length (mm)	432	432
Fin Type	Flat	Flat
FPI	7	7
Fin Thickness (mm)	0.19	0.19

Designs Summary



	Baseline	Design 1	Design 2	Design 3	Design 4
Tube Diameter (mm)	6.5	5	5	5	5
Tubes per Bank	8	8	8	8	8
Tube Banks	2	2	2	2	2
Horizontal Spacing (mm)	22.75	22.75	22.75	22.75	22.75
Vertical Spacing (mm)	26	26	26	26	26
Tube Length (mm)	432	432	432	432	432
Fin Type	Flat	Flat	Flat	Flat	Flat
FPI	7	7	7	7	7
Fin Thickness (mm)	0.19	0.19	0.19	0.19	0.19

Circuits Evaluation

All designs were evaluated using the same refrigerant inlet conditions, estimated based on limited information

	Freezer Circuit	Refrigerator Circuit
Pressure (psi)	75.9	72.6
Discharge temperature (°F)	126	121
Refrigerant mass flow rate (lb/h)	3.38	2.37
Refrigerant Used	Isobutane (R600a)	
Air Inlet Temperature (°F)	90	
Air Flow Rate (CFM)	100	

Circuits Analysis

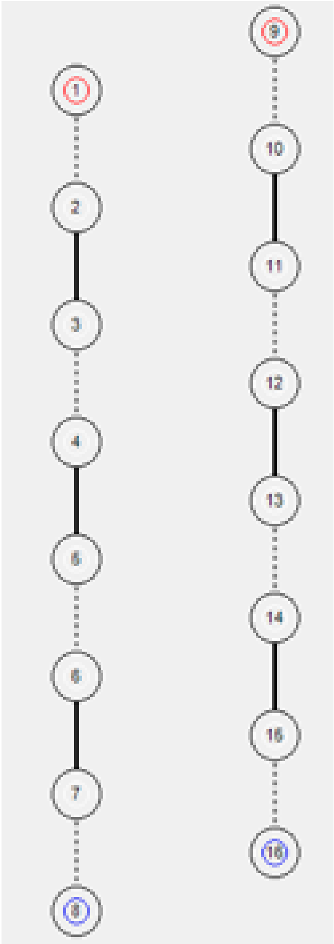
		Baseline		Design 1		Design 2F		Design 2R		Design 3		Design 4	
	Total Air HT Area (m^2)	2.13		2.15		2.13		2.15		2.15		2.15	
	Total Capacity (W)	238		247		235		**248**		247		248	
	Air Pressure Drop (Pa)	3.34		3.92		3.9		**3.9**		3.9		3.9	
	Refrigerant Pressure Drop (Pa)	286		570		607		583		582		547	
	Internal Volume (cc)	167.1		111.4		111.4		**111.4**		111.4		111.4	
	Fin Material Mass (g)	544		544		544		544		544		544	
	Tube Material Mass (g)	560		256		256		**256**		256		256	
	Circuit	Freez	Refrig	Freez	Refrig	Freez	Refrig	Freez	Refrig	Freez	Refrig	Freez	Refrig
Both Circ On	Capacity (W)	136	101	144	102	147	88	**145**	**103**	147	101	147	102
Both Circ On	Subcooling (°F)	n/a	0.7	0.9	2.8	5.2	n/a	1.9	3.9	4.0	0.0	4.1	2.0
One Circ On	Capacity (W)	144	102	145	102	148	104	148	104	148	104	148	104
One Circ On	Subcooling (°F)	0.1	2.2	2.1	4.1	7.0	6.9	6.9	7.0	7.1	6.8	7.0	6.8

Circuits Analysis

Series designs perform better than baseline circuit design (parallel) when only one circuit is running

All circuits in series with equivalent face area and number of tubes perform equally when one circuit is running - therefore, all designs should be evaluated for two-circuit performance

Should use Design 2R, focus on two circuit performance

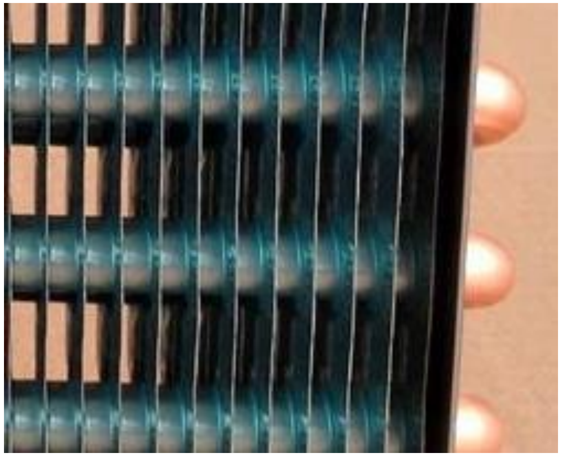


Optimization Study

- Goal: Equal performance to the baseline while reducing refrigerant charge to R600a limits
- Multi-objective genetic algorithm (MOGA) was used to solve the optimization problem
- 5mm copper tubes was used to minimize charge
- Constraints:
  - » Heat rejection ≧ to baseline
  - » Subcooling ≧ to baseline
  - » Saturation temp. within 1C of baseline
  - » Air dP within acceptable range for existing fan

Optimization Study

- HX design variables using 5mm OD tube :
  - » Heat exchanger length
  - » Fin density
  - » Horizontal tube spacing
  - » Vertical tube spacing
  - » Fin geometry

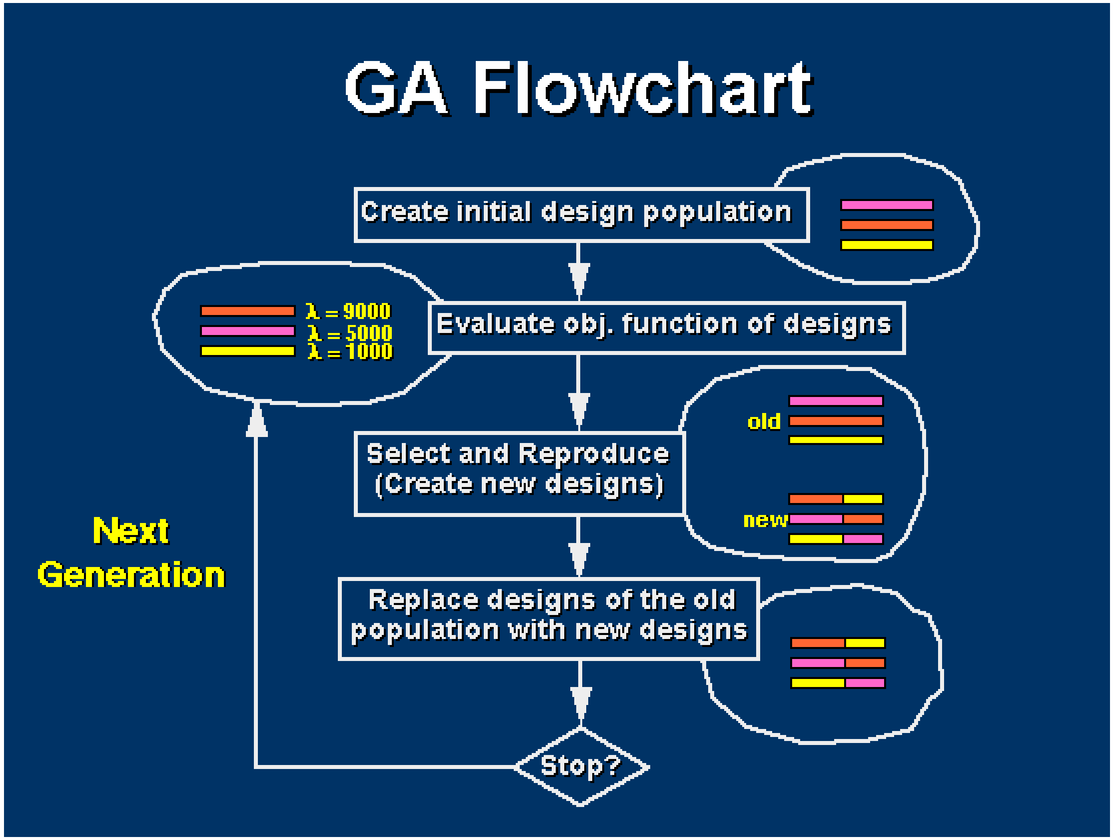


Optimization Study

- Multi-objective genetic algorithm (MOGA) explained:

GA is a type of evolutionary algorithm

A ***population*** of possible solutions is evaluated in each iteration



Optimization Study

- Multi-objective algorithm:
  - » Multiple objective functions are evaluated

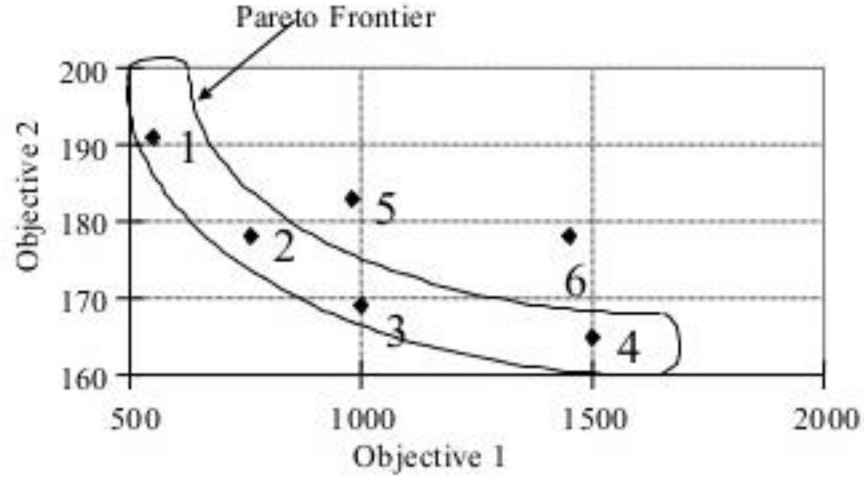
Single objective
(for example, weighted sum)

Decision made before the search

$$FO_i = \sum_{j=1}^{q} w_j F_j \qquad \begin{cases} 0 \le w_j \le 1 \\ \sum w_j = 1 \\ 0 \le F_j \le 1 \\ 0 \le FO_i \le 1 \end{cases}$$

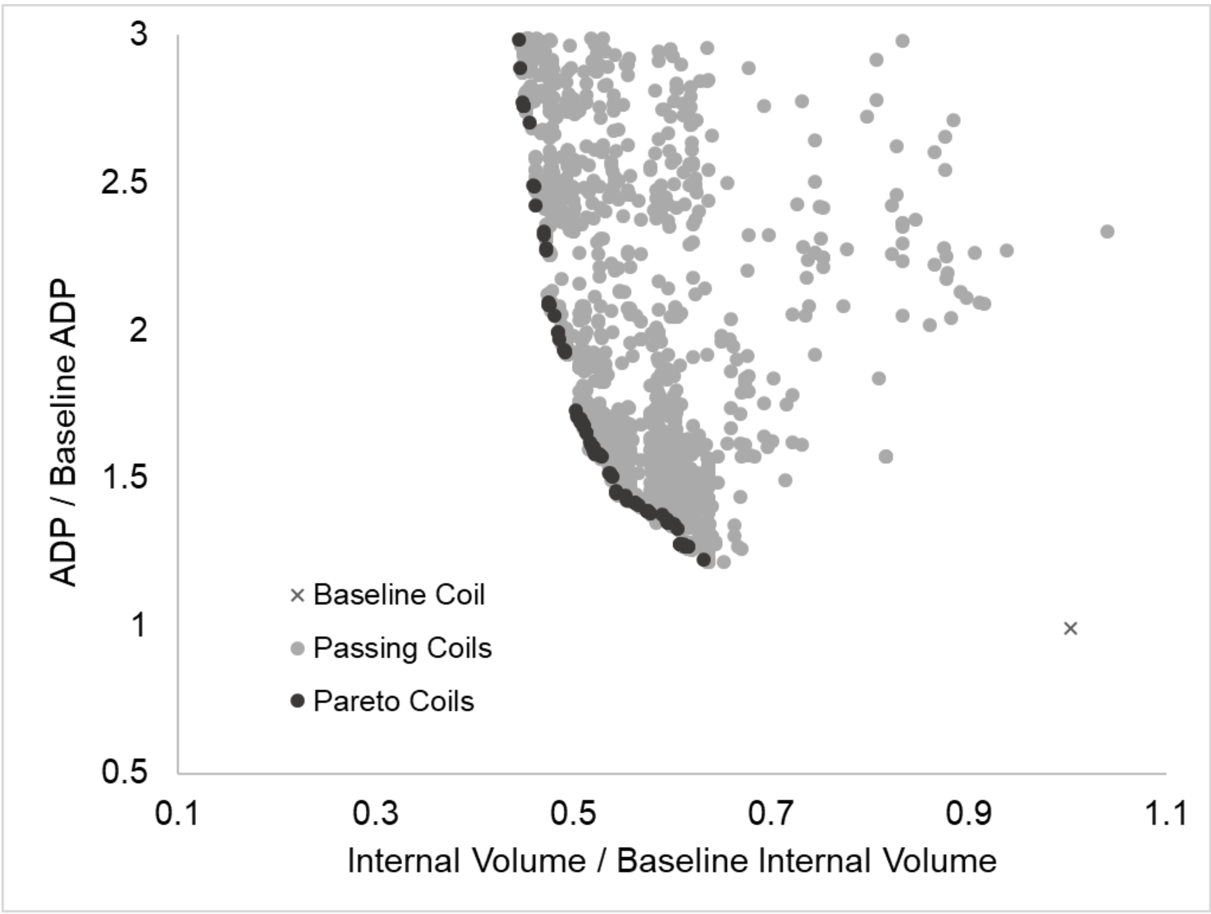
Multiobjective optimization

Decision made after the search



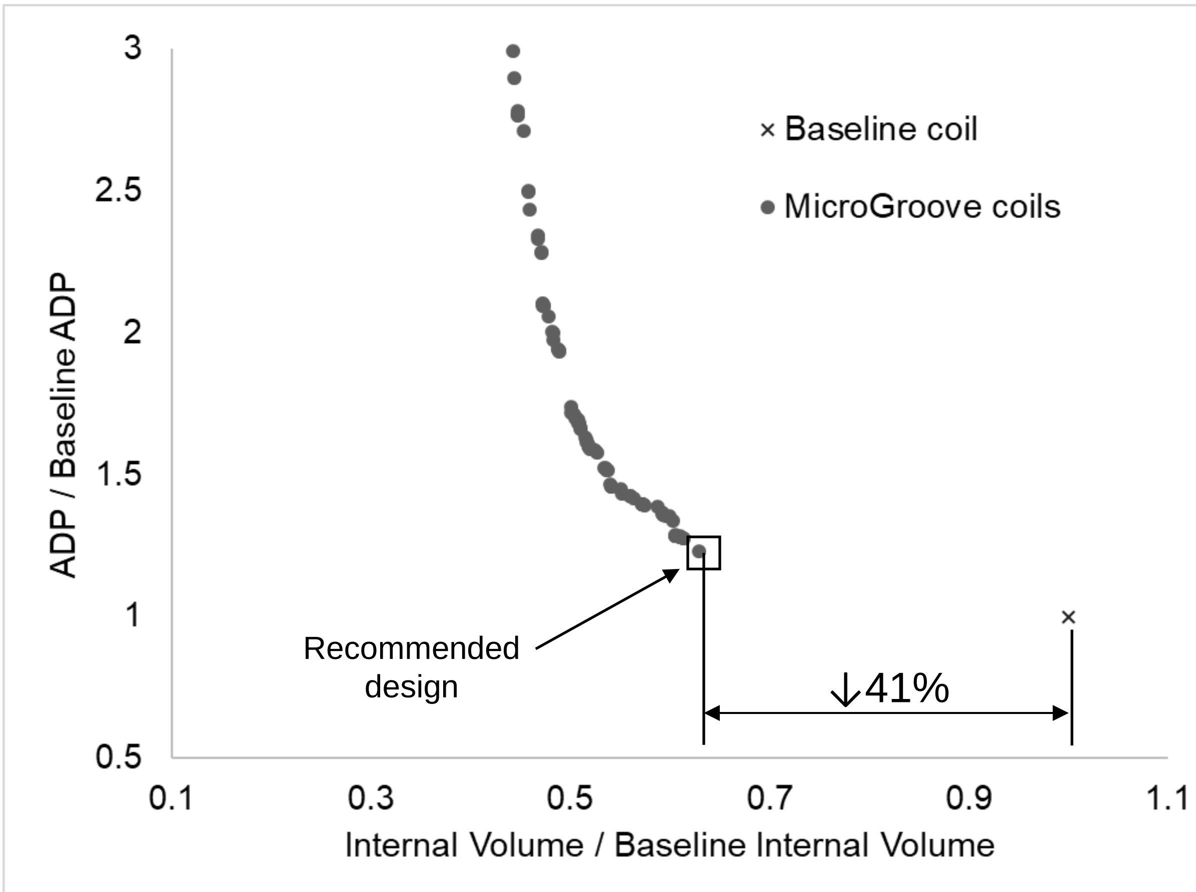
Optimization Study

- MOGA results:



Optimization Study

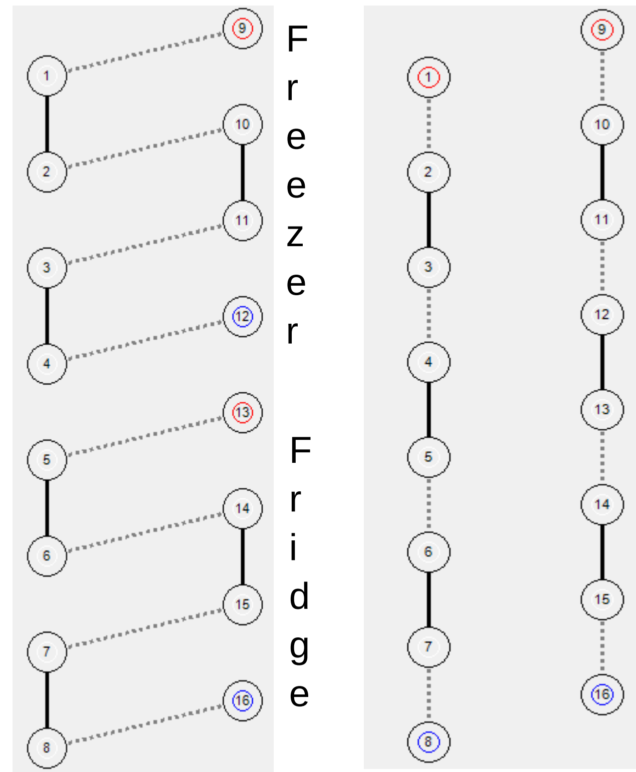
- MOGA results:



Prototype Construction

Selected prototype geometry to reduce charge:

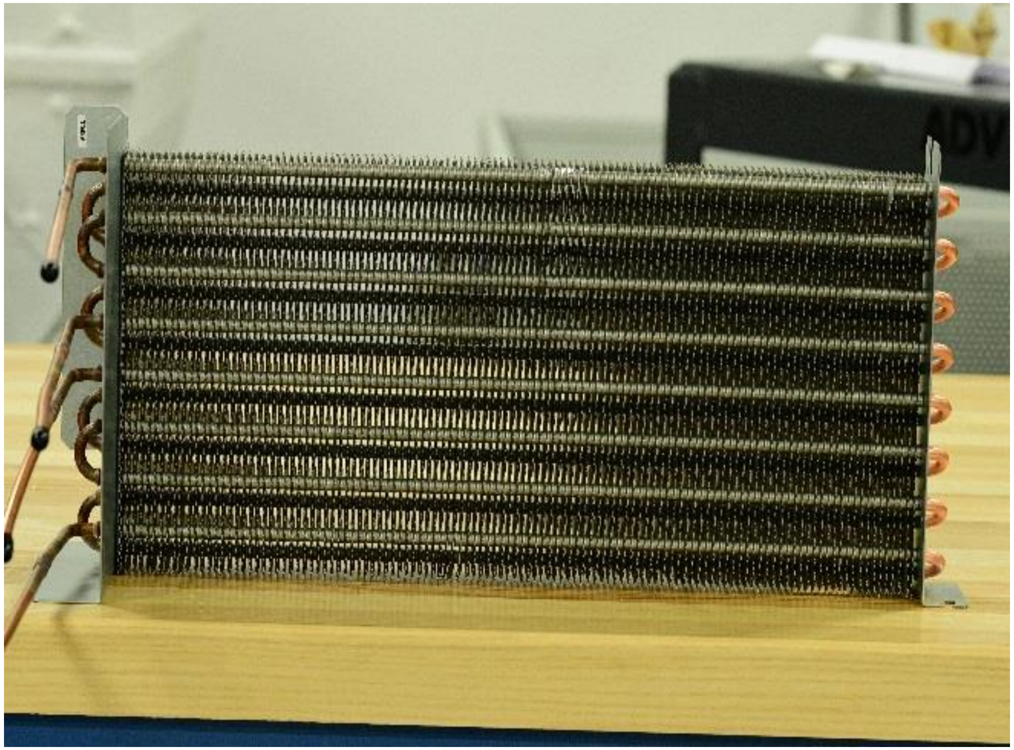
	Baseline	New
Tube Diameter (mm)	6.5	**5**
Tubes per Bank	8	8
Tube Banks	2	2
Horizontal Spacing (mm)	22.75	22.75
Vertical Spacing (mm)	26	26
Tube Length (mm)	432	432
Fin Type	Wavy	**Flat**
Fin Density (fpi)	7	7
Fin Thickness (mm)	0.19	**0.12**



Baseline New

Prototype Construction

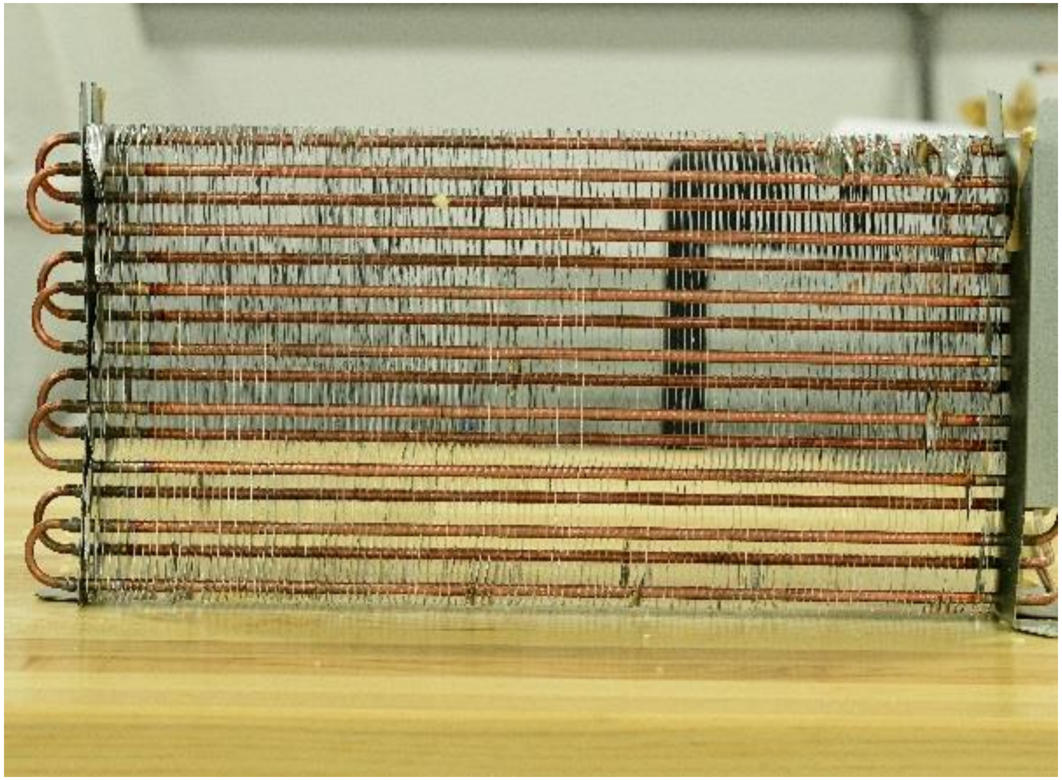
Baseline



Wavy fin

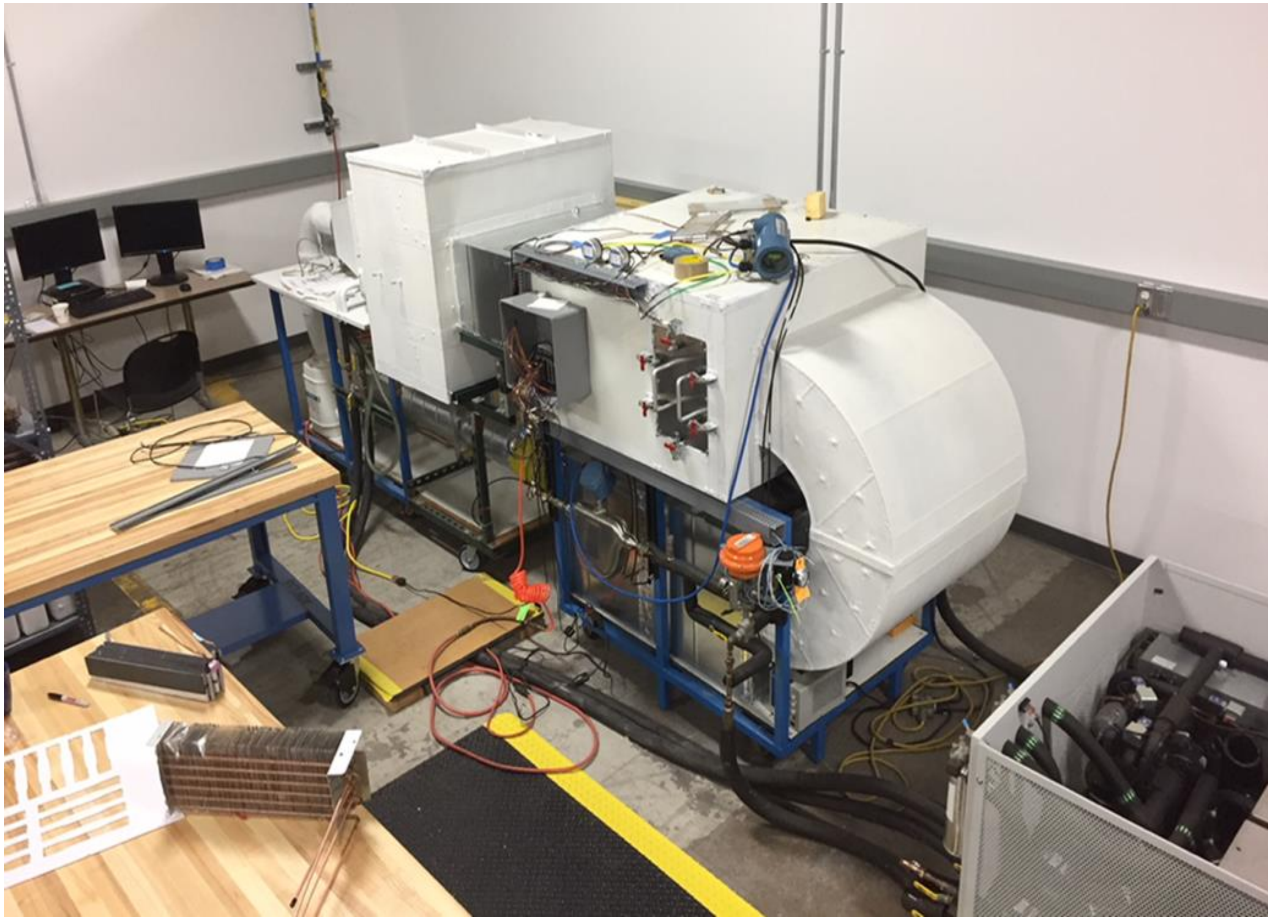
Prototype Construction

New



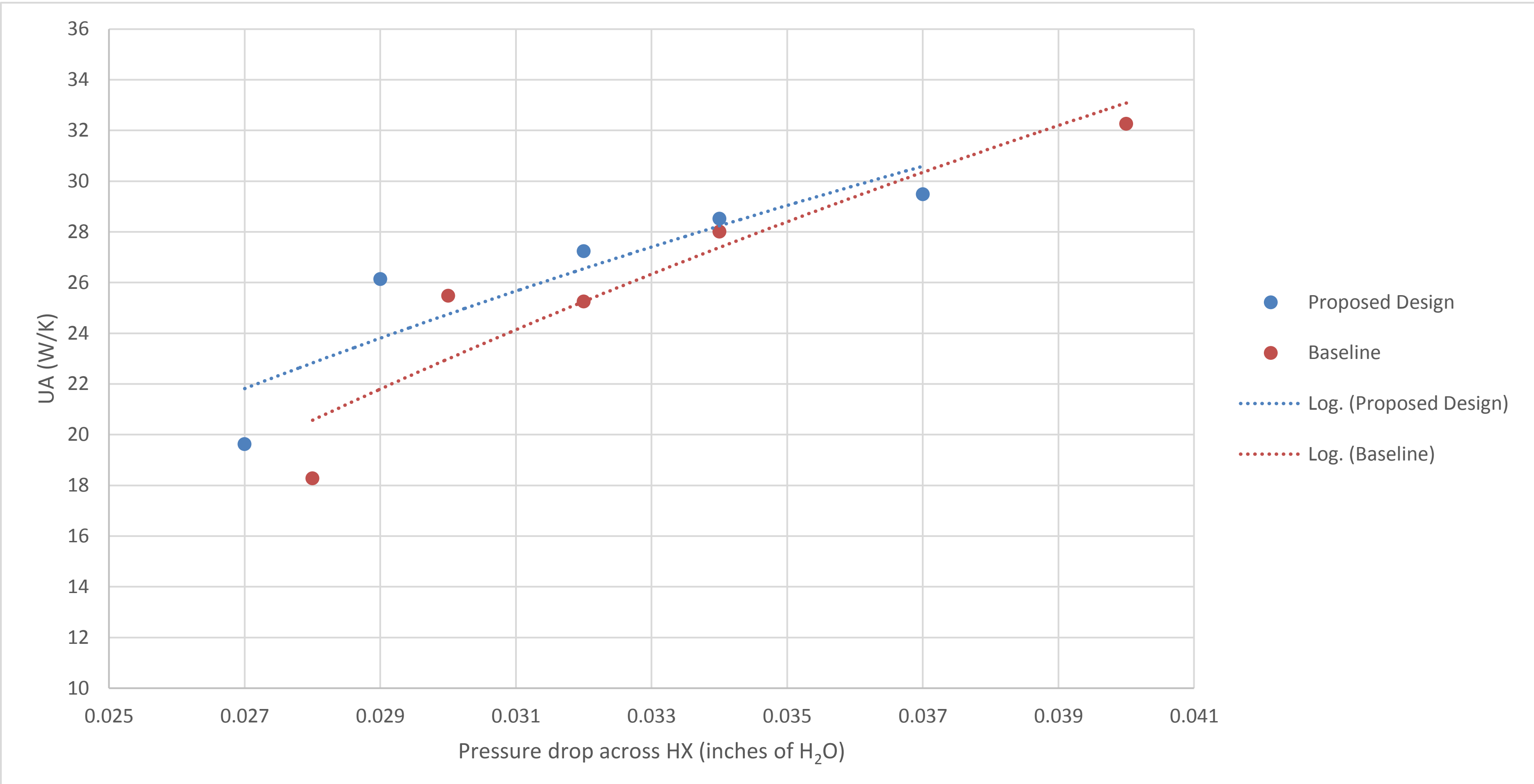
No collar, flat fin

Testing



Hot water calorimeter

Airside Test Results



Overall conductance vs. pressure drop

Summary and Conclusions

- Summary:
  - » New HX design using 5mm copper tube vs. 6.5mm has
    - 37% lower internal volume
    - 25% weight reduction
    - 8% performance improvement (Can be used)
- Conclusion:
  - » Methodology used (MOGA) successful in finding optimized designs
  - » 5mm copper tube MG heat exchanger can maintain performance and allow for lower refrigerant charge in a smaller, lighter envelope, suitable for R290 and R600a natural refrigerants, and others.