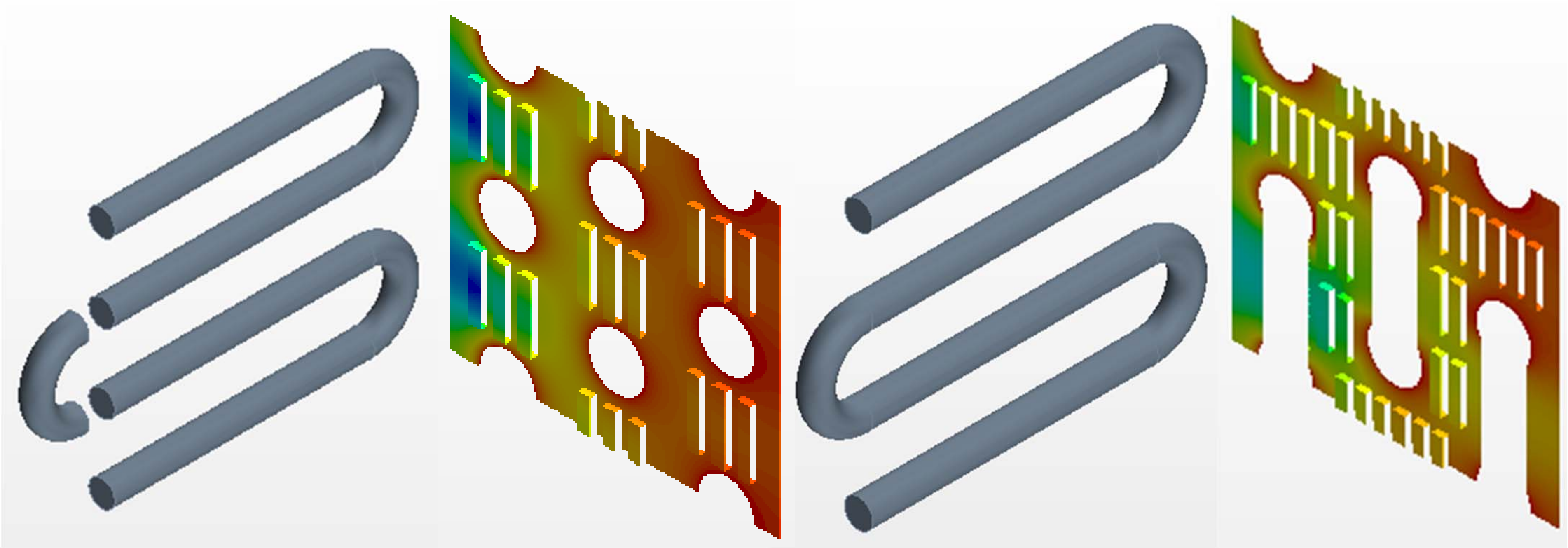
Advanced Serpentine Heat Exchangers

2017 Building Technologies Office Peer Review



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Daniel Bacellar
bacellar@optimizedthermalsystems.com
Optimized Thermal Systems, Inc.

Project Summary

Timeline:

Start date: 10/2016

Planned end date: 10/2019

Key Milestones

1. Develop Optimized Fin Geometry; 08/2017
2. Construct Prototype Heat Exchangers; 03/2018
3. Commercialization Plan; 10/2019

Budget:

Total Project $ to Date: 23,937.97

- DOE: $17,884.40
- Cost Share: $6,053.57

Total Project $: 663,397

- DOE: $509,563
- Cost Share: $153,834

Key Partners:

Optimized Thermal Systems, Inc.
Heat Transfer Technologies (HTT)
United Technologies Research Center (UTRC)

Project Outcome:

Conceptualize **serpentine heat exchangers** for HVAC application, aiming **leakage reduction**.

Design & Optimize novel “dog-bone” fin concepts that result in **equivalent or better performance** than current state-of-the-art tube-fin heat exchangers.

Prototype, validate and commercialize.

Purpose and Objectives

Problem Statement: develop heat exchanger design and manufacturing solutions aiming to significantly reduce the direct and indirect impacts of refrigerant leakage in heating, ventilating, air conditioning and refrigeration (HVAC&R) systems.

Main Objectives:

- Develop serpentine heat exchangers (SHX) with equivalent or better performance than current state-of-the-art HX's
- Eliminate 90% of the joints in a 3-ton residential AC / heat pump system
- Develop designs that could be mass produced

Target Market and Audience: Heat Pumps and Air Conditioners – **31%** of end energy use in residential and commercial buildings in 2014

Impact of Project:

a) New SHX concepts with reduced leakage potential – **Year 1**
b) New tooling and manufacturing approaches – **Years 1, 2**
c) SHX Design & Optimization; Prototype & Validation – **Year 2**
d) Commercialization Plan – **Year 3**
e) Heat Pumps with reduced leakage potential – 2-3 Years after project

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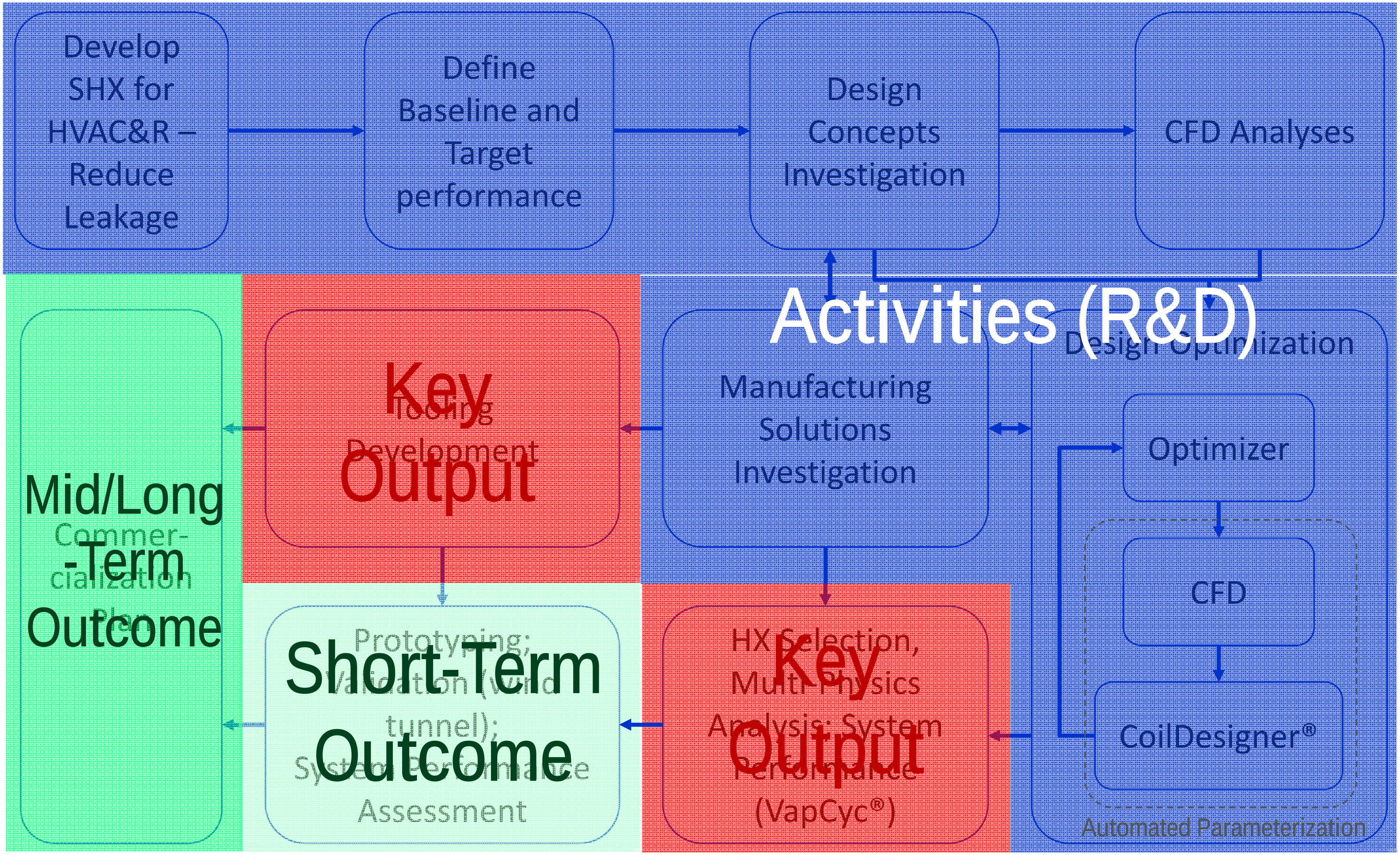
Approach



Activities (R&D)

Develop SHX for HVAC&R – Reduce Leakage

Define Baseline and Target performance

Design Concepts Investigation

CFD Analyses

Design Optimization

Optimizer

CFD

CoilDesigner®

Automated Parameterization

Manufacturing Solutions Investigation

Key Output

Tooling Development

Key Output

HX Selection, Multi-Physics Analysis; System Performance (VapCyc®)

Short-Term Outcome

Prototyping; Validation (wind tunnel); System Performance Assessment

Mid/Long-Term Outcome

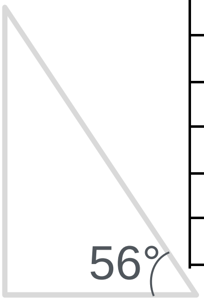
Commer-cialization Plan

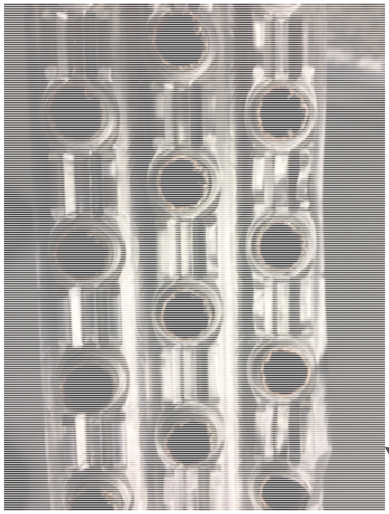
Progress and Accomplishments - Tasks & Milestones

Task	Milestone	Time frame	Status
Task 1.1: Baseline Selection	**Milestone 1.1:** Provide details of selected baseline systems and heat exchangers and provide rationale for selection	10/16 – 11/16	✓ Baseline selected: Carrier state-of-the-art 3Ton unit ✓ CoilDesigner® verification
Task 1.2: Initial Performance Simulations.	**Milestone 1.2:** Demonstrate that a non-optimized enhanced "dog-bone" type fin can achieve heat transfer and pressure drop performance within **20%** of the baseline fin through CFD simulations.	11/16 - 02/17	✓ CoilDesigner® optimization studies ✓ Challenges identification ✓ Baseline re-designed with "dog-bone" fin + CFD simulations ✓ CoilDesigner® verification → <20% of baseline performance

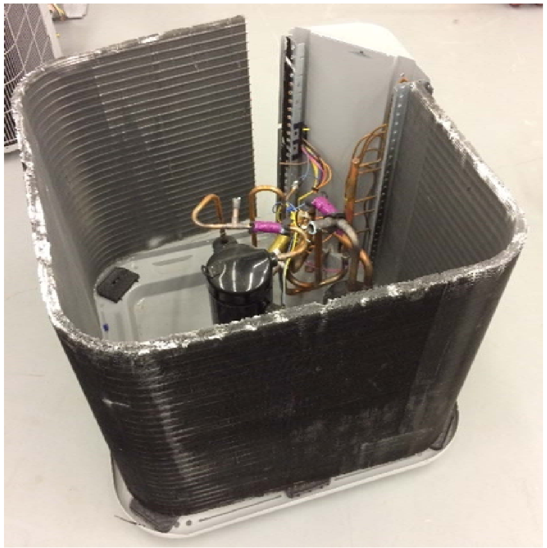
Baseline Selection

Outdoor HX tube diameter	7mm (0.291″ expanded OD)
Outdoor HX # tubes	28
Outdoor HX fin type	Lanced
Outdoor HX fin pattern and geometry details*	0.85″ X 0.736″
Outdoor HX air flow rate	3167 CFM
Indoor HX tube diameter	3/8″ (0.396″ expanded OD)
Indoor HX # tubes	24
Indoor HX fin type	Lanced
Indoor HX fin pattern and geometry details*	1″ X 0.75″
Indoor HX air flow rate	1200 SCFM
Compressor model number	APG031KA

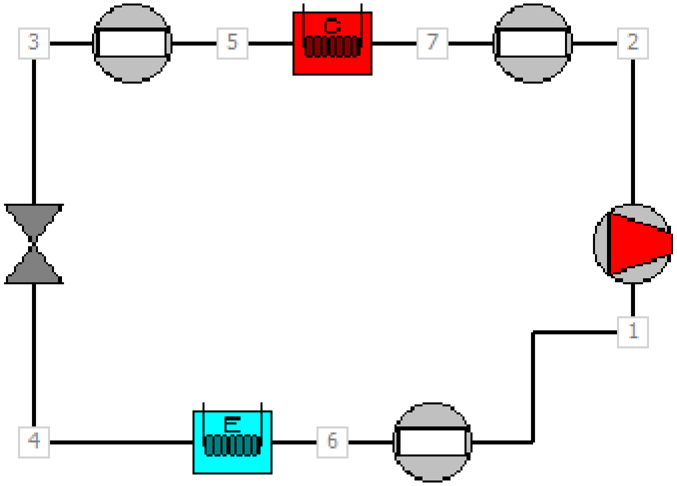


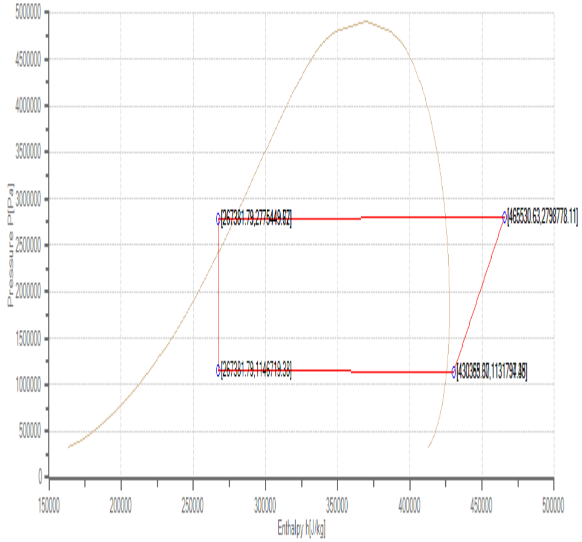


Inner grooved



Baseline Selection – Performance Assessment

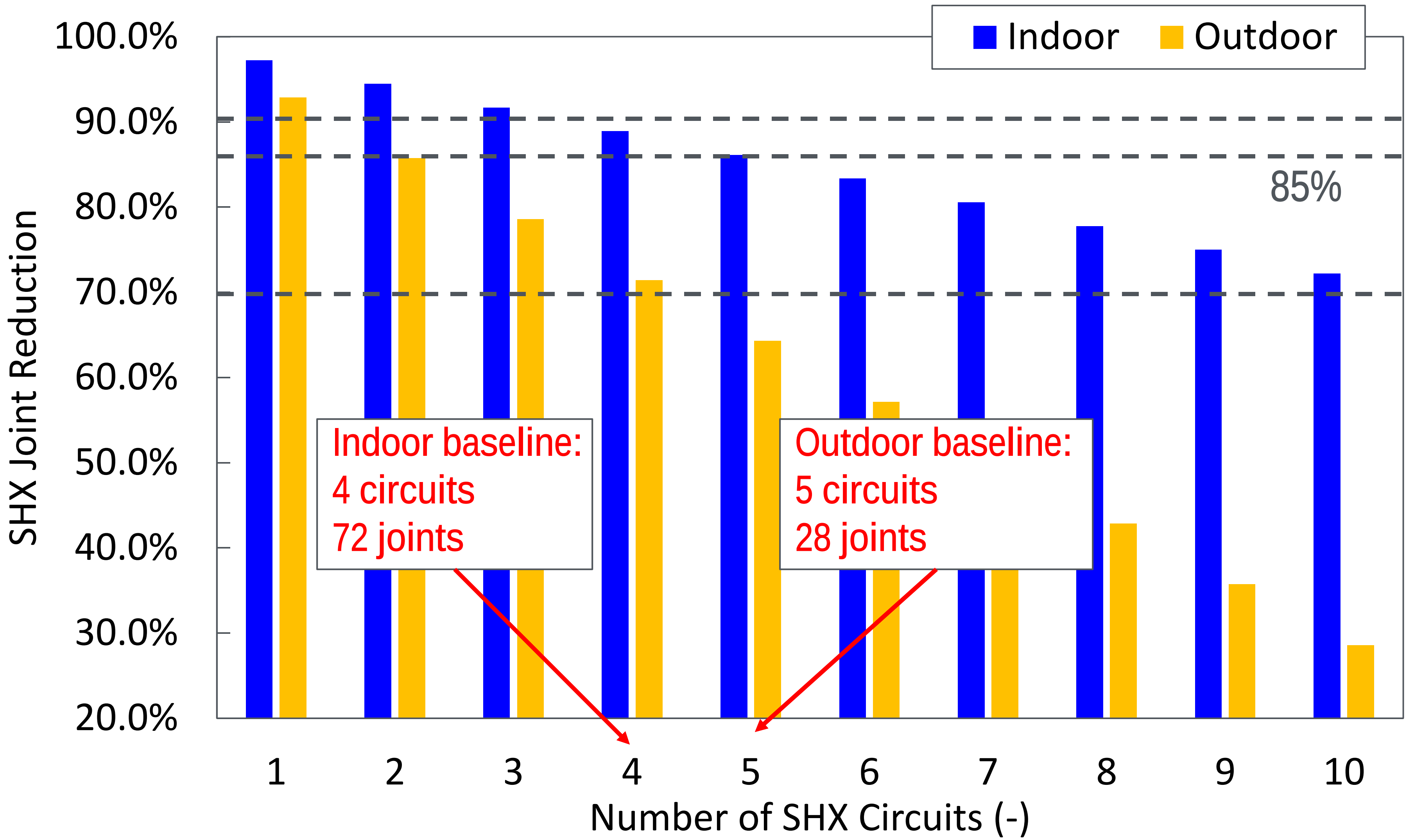




VapCyc® System Results		
System COP	4.6	-
Power Consumption	2234	W
Refrigerant Charge	1.48	kg
Subcooling	5.5	K
Superheat	4.0	K

CoilDesigner® Heat Exchanger Results	Unit	Baseline	
		Indoor HX	Outdoor HX
Capacity	kW	10.31	12.58
Air flow rate	cfm	1200	3149
Pressure	kPa	1147	2798
Inlet Temperature	K	285	345
Inlet Quality	-	0.228	-
Air Pressure Drop	Pa	45.8	12.2
Air Heat Transfer Coefficient	W/m².K	101.3	108.1
Refrigerant Pressure Drop	kPa	14.9	23.3

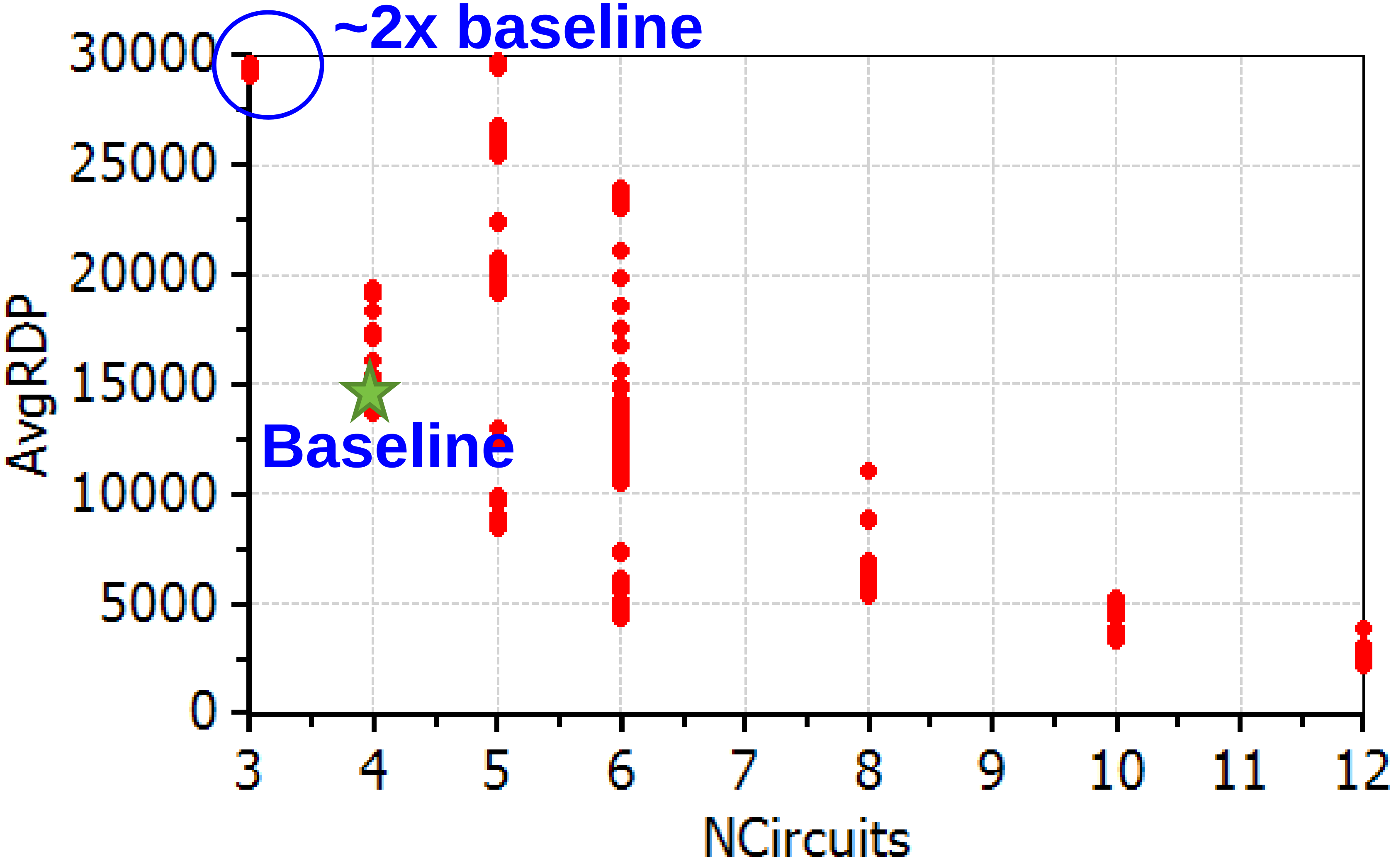
Initial Analysis – Circuiting vs. Joint Reduction



Indoor baseline:
4 circuits
72 joints

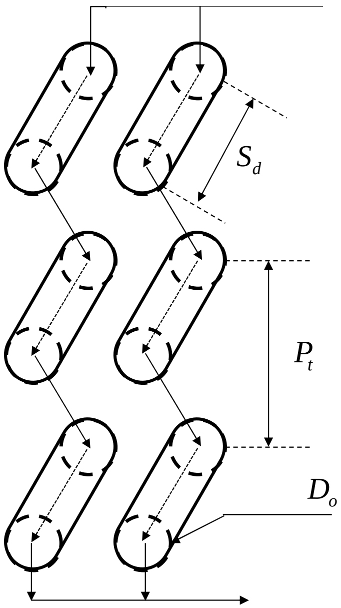
Outdoor baseline:
5 circuits
28 joints

Initial Analysis - Ref. ΔP vs. N° circuits (Indoor HX)

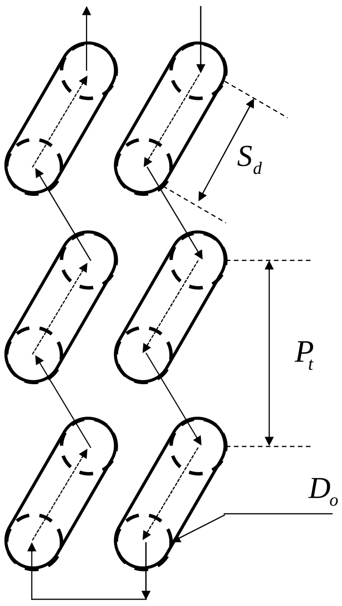


Initial Analysis – Fin “dog-bone” cut (Indoor HX)

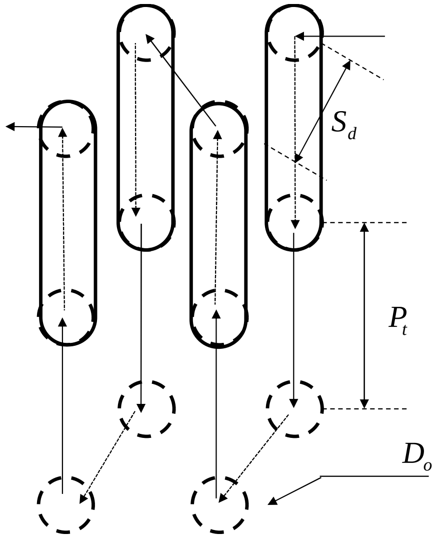
Semi-cross Parallel

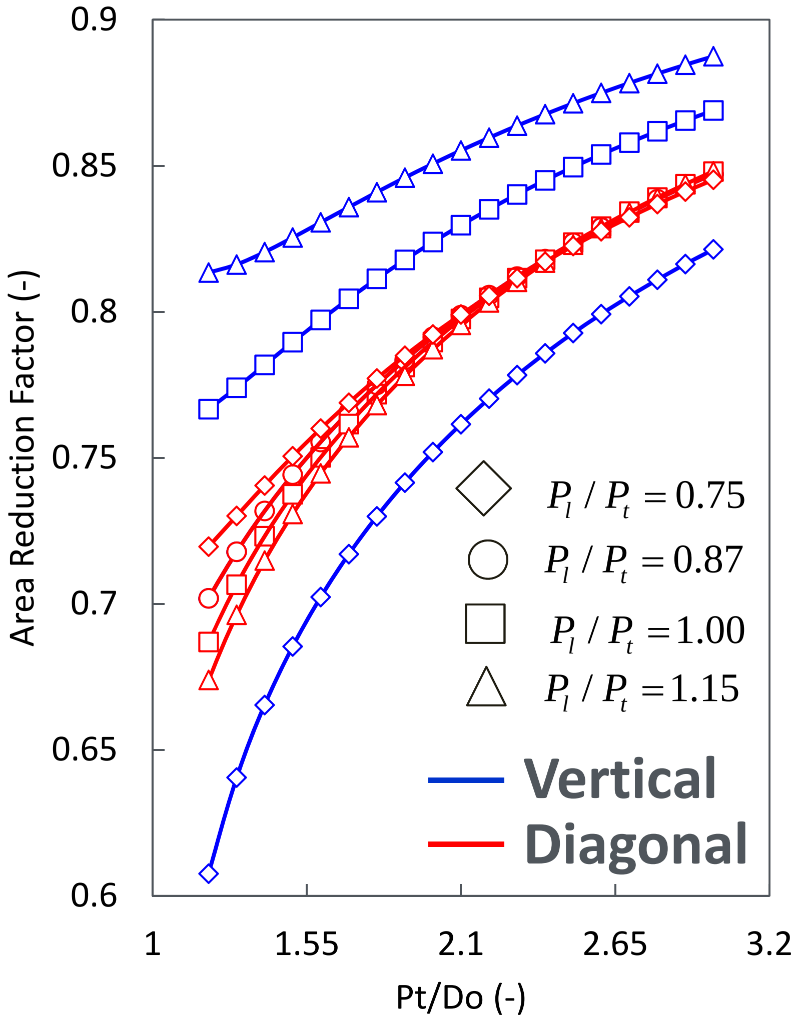


Semi-cross Counter

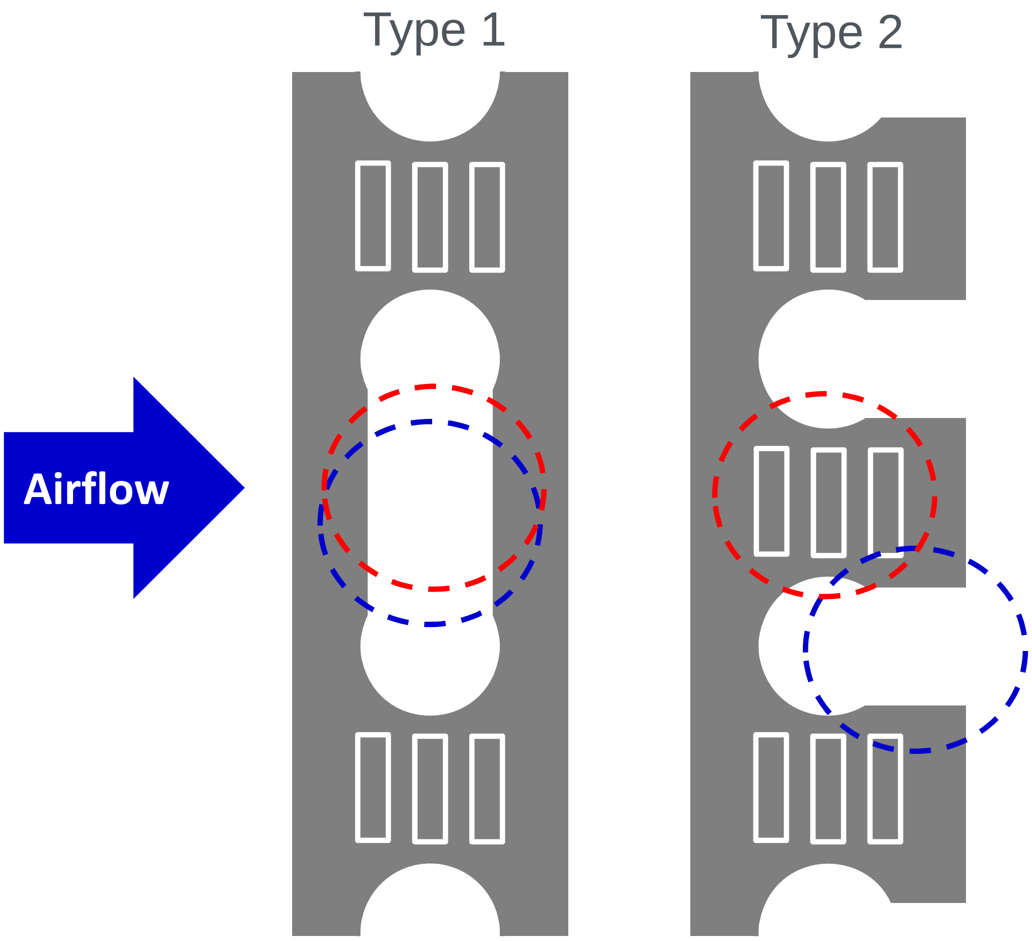


Full-cross Counter





Initial Analysis – Fin “dog-bone” cut (Outdoor HX)



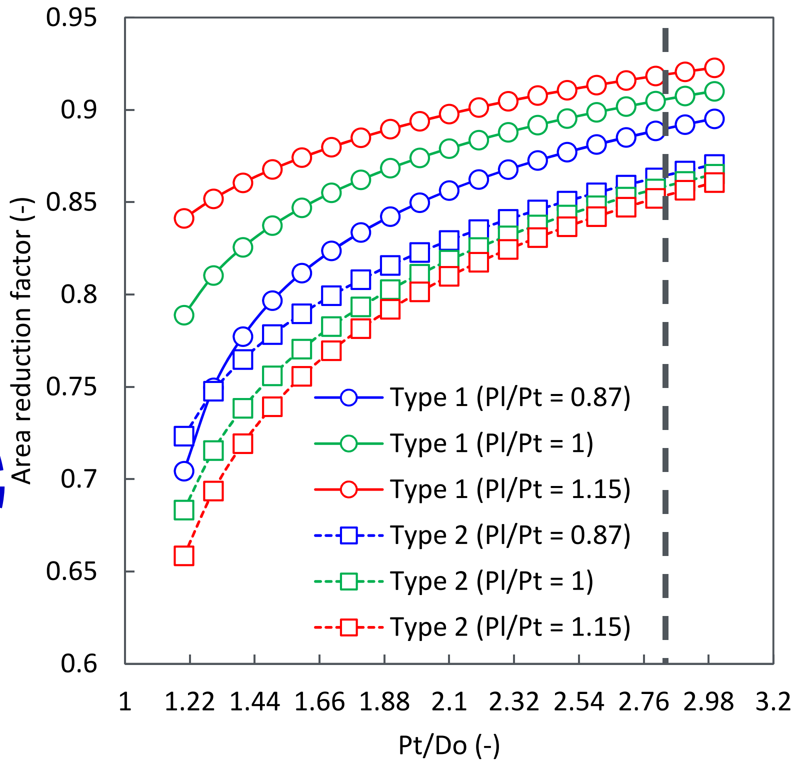
Minimum free flow area **high u**

Reduced enhancements

Wake flow

low u

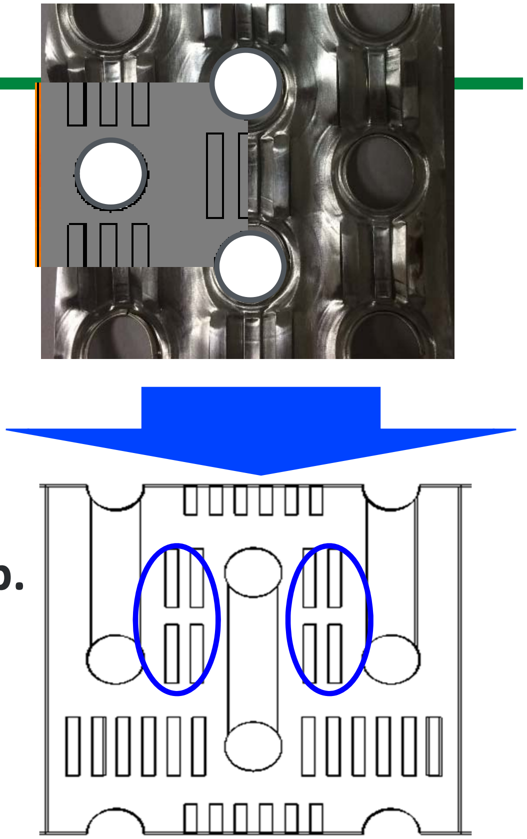
No enhancements reduction



Initial Analysis – Manufacturing Considerations

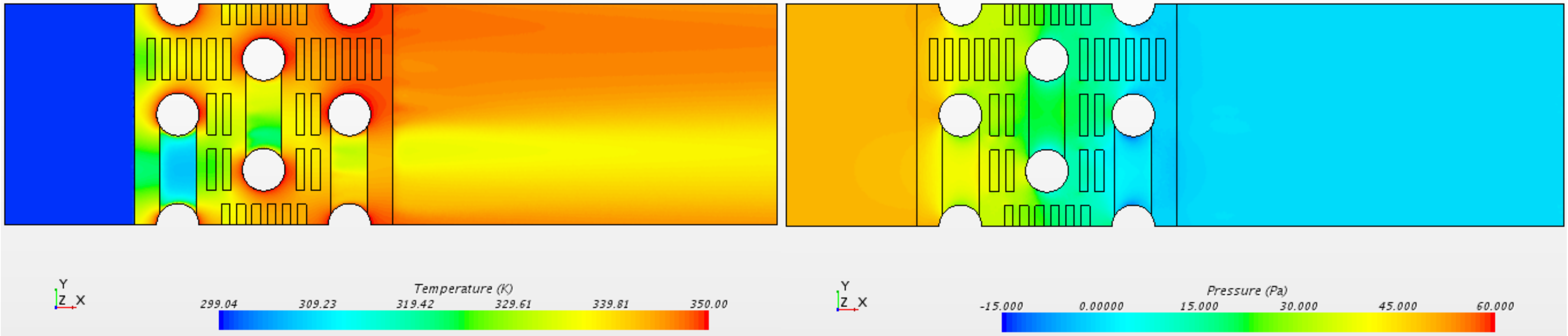
- Tubes
  - Minimum diameter: 5.0mm
  - Minimum bend radius (Do): 1.5
  - Tube length: N/A
  - Pitch angle: N/A
- Fins
  - Minimum tube-fin enhancement distance: 2.0mm
  - Max fin density: ~20 FPI
  - Assembly could potentially damage enhancements; yet to be confirmed

Baseline Modification – Indoor HX



CFD Settings

- Mesh size: 1.0mm (polyhedral elements)
- Boundary layer: 3.0mm, 10 layers, 1.2 growth
- Uncertainty analysis - GCI (on going task)
- Dry air – ideal gas
- K-e Realizable turbulence model
- B. C.: uniform inlet velocity/temperature; constant wall temp.
- Steady-State



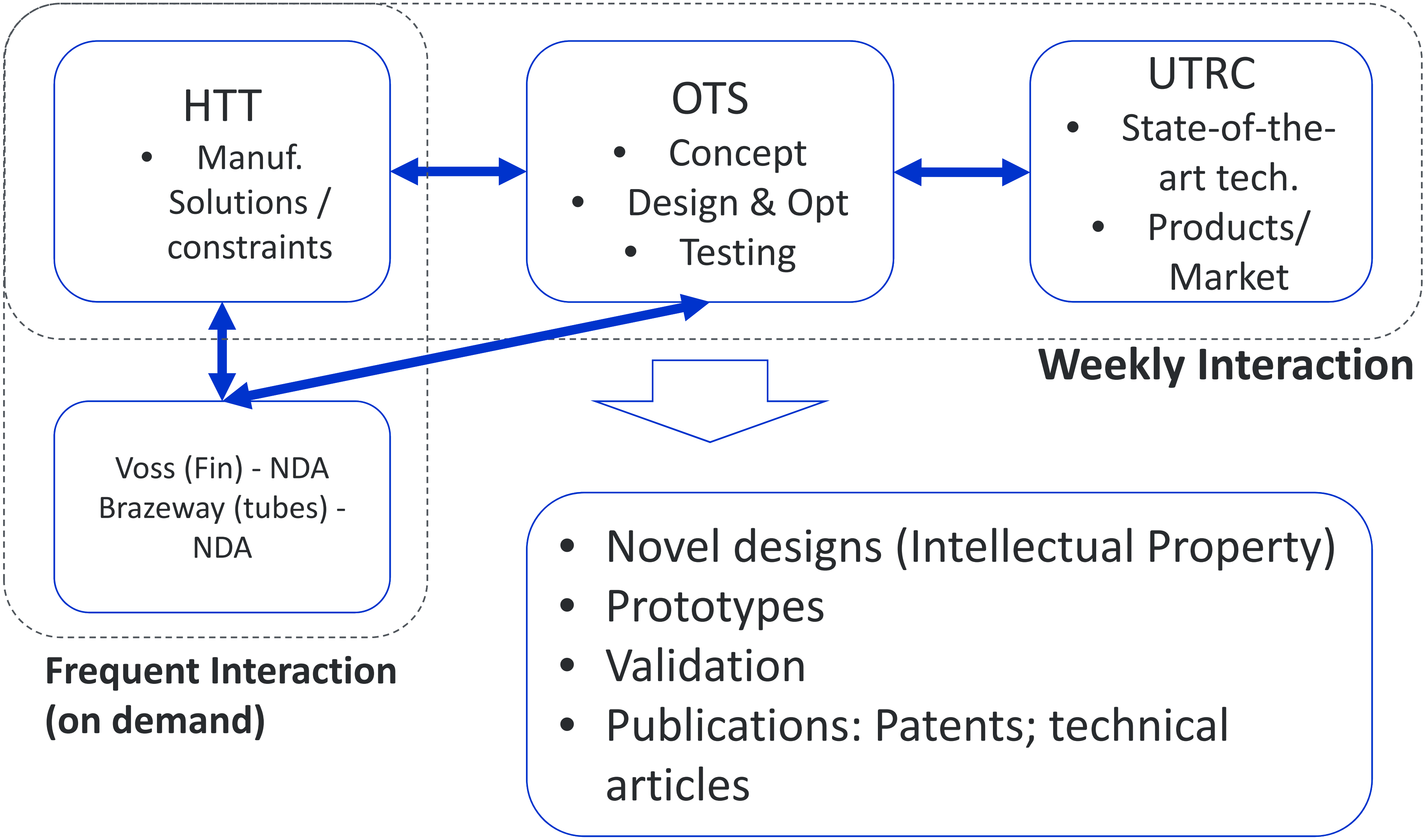
Milestone 1.2 Accomplishment – Indoor HX

Metric	Unit	Baseline	SHX-POF-001	Rel Diff
Do	m	0.0098	0.0098	0.00%
Pl	m	0.019	0.0198	4.21%
Pt	m	0.0254	0.0254	0.00%
Sd	m	0.0229	0.0235	2.93%
FPI	m	16	16	0.00%
Nbanks	-	3	3	0.00%
Nrows	-	24	24	0.00%
Ncircuits	-	4	4	0.00%
Face area	m^2	0.263	0.263	0.0%
Joints	-	72	8	-88.89%
hair	$W/m^2.K$	101.1*	113.3**	12.07%
Ao	m^2	16.85	14.24	-15.47%
ΔPair	Pa	45.82*	49.69**	8.45%
ΔPref	kPa	14925	14661	-1.77%
Q	W	10351	10187	-1.58%

< 20%

**Wang et al. (2001)   **CFD*

Project Integration and Collaboration



HTT
- Manuf. Solutions / constraints

OTS
- Concept
- Design & Opt
- Testing

UTRC
- State-of-the-art tech.
- Products/ Market

Voss (Fin) - NDA
Brazeway (tubes) - NDA

Weekly Interaction

Frequent Interaction (on demand)

- Novel designs (Intellectual Property)
- Prototypes
- Validation
- Publications: Patents; technical articles

Next Steps and Future Plans

- **Task 1.2: Initial Performance Analysis**
  - Finalize CFD analyses (uncertainty analysis; outdoor HX)

- **Task 1.3: Material Simulation and Selection**
  - Study other modifications to the baseline to make it manufacturable
  - Indoor coil: review copper and aluminum options
  - Outdoor coil: exploring options (Task 1.2)
  - HTT begins exploring material and manufacturing options

- **Task 1.4: Benchtop Testing of Brazing Methods (HTT)**

REFERENCE SLIDES

Project Budget

Budget History					
10/2016 – FY 2017		FY 2018		FY 2019 – 10/2019	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$100,432	$25,297	$253,488	$68,230	$155,643	$60,307

Project Plan and Schedule

Project Schedule		
Project Start: 10/2016	🟦	Completed Work
Projected End: 10/2019	⬛	Active Task (in progress work)
	♦	Milestone/Deliverable (Originally Planned)
	◆	Milestone/Deliverable (Actual)

Task	FY2017				FY2018				FY2019			
	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)
Past Work												
1.0 Intellectual Property (IP) Management Plan	🟦◆											
2.1 Baseline Selection	🟦◆											
2.2 Initial Performance Simulations	🟦	🟦◆										
Current/Future Work												
2.3 Material Simulation and Selection		⬛	⬛◆									
2.4 Benchtop Testing of Brazing Methods			⬛	⬛◆								
3.1 Optimization Definition and Manufacturing Considerations				⬛◆								
3.2 Develop Optimized Fin Geometry				⬛	⬛◆							
4.1 Design Fin Tooling					⬛◆							
4.2 Construct Prototype Heat Exchangers						⬛◆						
5.1 Heat Exchanger Performance Testing							⬛	⬛◆				
5.2 Mechanical / Cyclic Testing								⬛	⬛◆			
6.1 Improve Manufacturing Techniques in Preparation for Commercialization									⬛◆			
6.2 System Level Integration										⬛	⬛◆	
6.3 System Level Testing											⬛	⬛◆
7.0 Develop Technology to Market Commercialization Plan											⬛	⬛◆