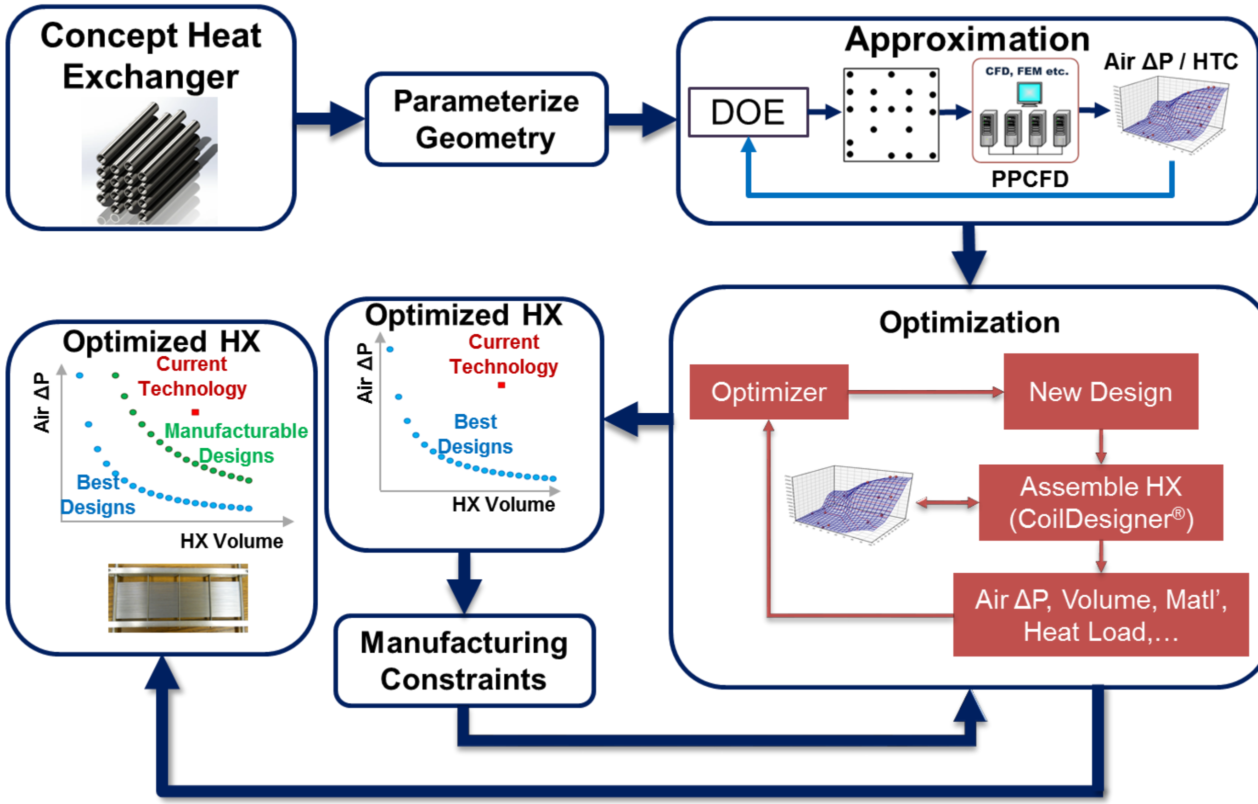
Miniaturized Air-to-Refrigerant Heat Exchangers

2015 Building Technologies Office Peer Review

20%+ Better



U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Reinhard Radermacher
raderm@umd.edu
University of Maryland College Park

Project Summary

Timeline:

Start date: 3/1/2013

Planned end date: 2/29/2016

Key Milestones

1. Design optimization, 3/30/14
2. Fabrication/testing, 1kW prototype, 1/30/2015
3. Fabrication/testing, 10kW prototype, 9/30/2015

Budget:

Total Budget: $1500K

Total UMD: $1050K

Total DOE $ to date for UMD: $881K

Total future DOE $ for UMD: $169K

Target Market/Audience:

Residential and commercial heat pump systems with various capacity scales.

Condenser as first choice of application

Key Partners:

Oak Ridge National Laboratory
Burr Oak Tool
Heat Transfer Technologies
International Copper Association
Luvata
Wieland

Project Goal:

Purpose: Develop next generation heat exchangers for heat pumps and air-conditioners

Target Performance: Miniaturized air-to-refrigerant heat exchangers with at least

- 20% lower volume
- 20% less material
- 20% higher performance

Target Market: To be in production within five years

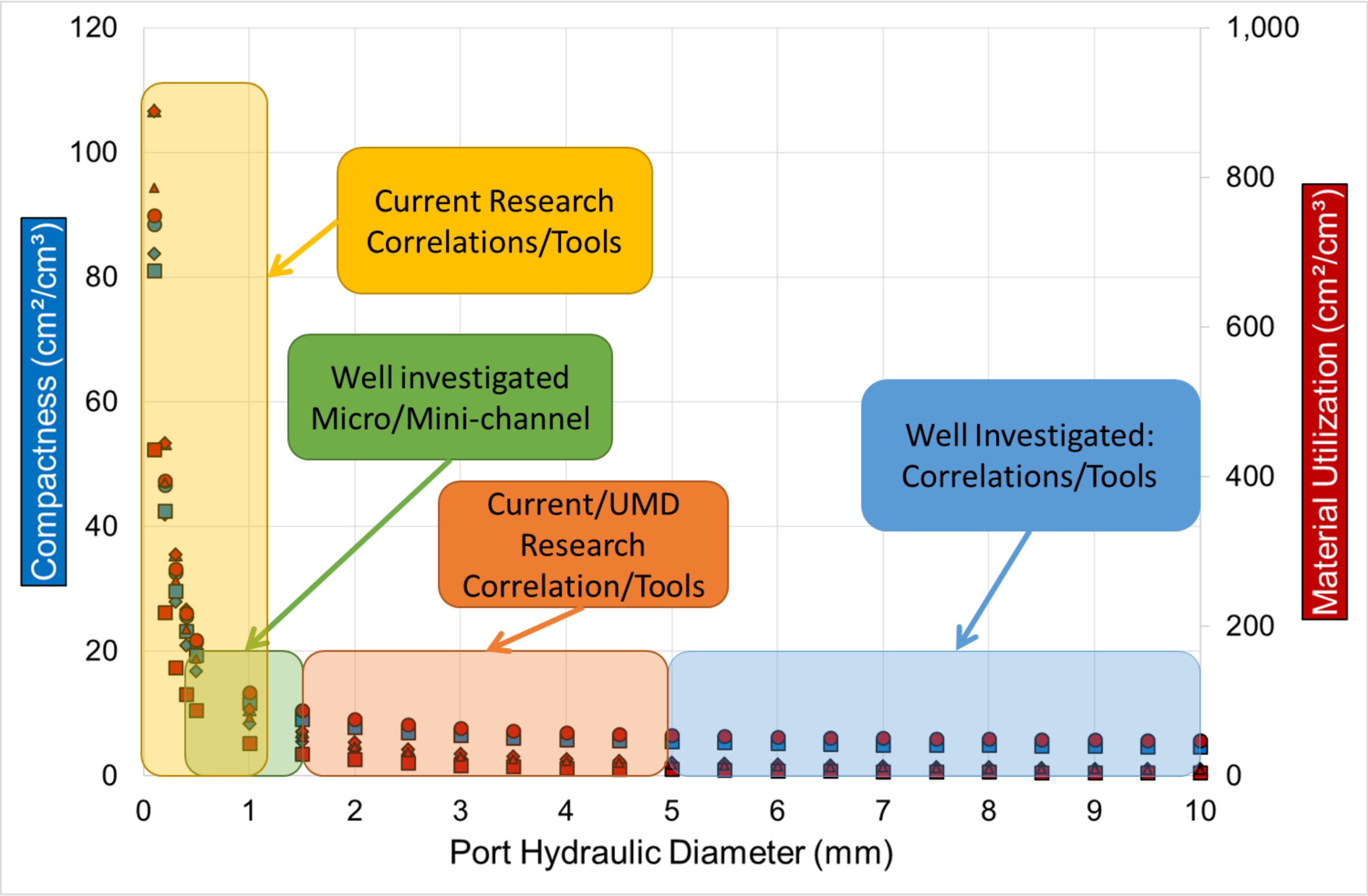
Purpose and Objectives

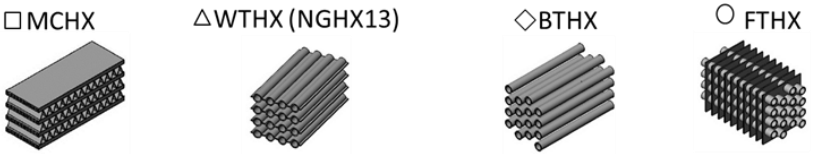
Problem Statement: Develop miniaturized air-to-refrigerant heat exchangers that are 20% better, in size, weight and performance, than current designs **AND**
In production within 5 Years

Target Market and Audience:
- Residential and commercial heat pumps and air-conditioners
- US Shipment of residential air-source equipment in 2011: 5.5 Million units
- US EIA 2009 Energy Consumption: 41.5% for space heating, 6.2% for AC
- Proposed heat exchanger technology will readily compete with current condenser designs for AC systems (3.7 M).

Impact of Project:
- Project deliverables include analyses tools and heat transfer correlations
- Heat exchangers (1 kW and 10 kW) that are at-least 20% better (size, weight and performance) than current designs, based on measured performance; a minimum of 3 prototypes to be fabricated and tested
- Manufacturing guidelines to facilitate production within 5 years

Future of Heat Exchangers





Approach

- Developed a comprehensive multi-scale modeling and optimization approach for design optimization of novel heat exchangers
    - Parallel Parameterized CFD
    - Approximation Assisted Optimization
- Build a test facility for air side performance measurement of heat exchangers
- Design, optimize and test 1 kW and 10 kW air-to-water and air-to-refrigerant heat exchangers
- Investigate conventional and additive manufacturing techniques
- Analyze and test system level performance of novel heat exchangers
    - Evaporator and condenser of a system based on same design

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Approach : Key Issues

- Lack of basic heat transfer and fluid flow data for design and analyses of air-to-refrigerant heat exchangers with small flow channels
- Availability for small diameter tubes
- Joining/manufacturing challenges
- Face area constraints
- Fouling and flow mal-distribution
- Wetting
- Noise and vibrations

Approach: Distinctive Characteristics

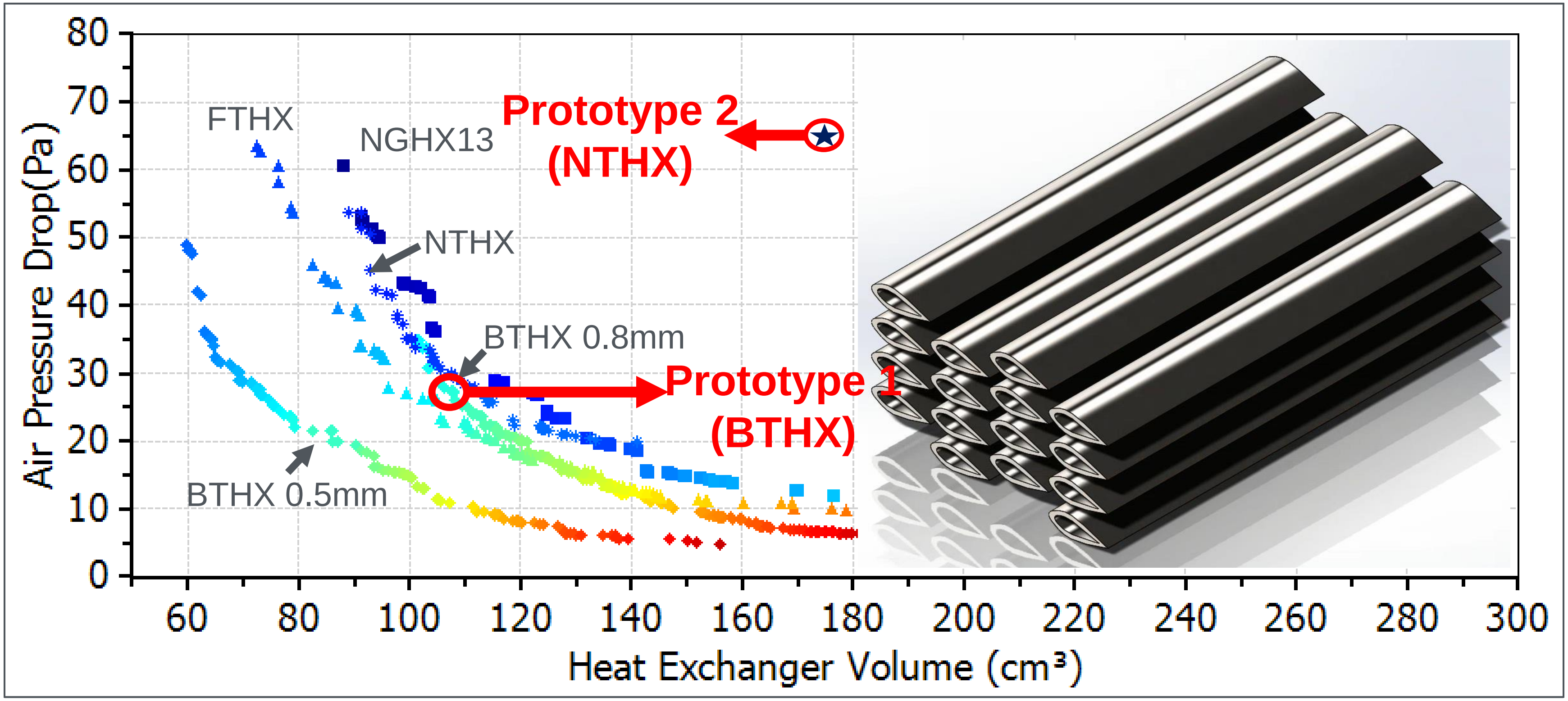
- Developed a comprehensive multi-scale modeling and optimization approach for design optimization of novel heat exchangers
  - Allows for rapid and automated CFD evaluation of geometries with topology change
  - More than 90% reduction in engineering and computation time
- Focus on small hydraulic diameter flow channels
  - Bridging the research gaps
  - Heat transfer, pressure drop correlations and design tools
- Prototype fabrication and testing is in progress, with target production within 5 years
  - Initial tests show, <10% deviation against predicted
- 20% size and weight reduction
  - Retrofit applications, limited load carrying capacity of roofs
  - Potential savings in logistics costs

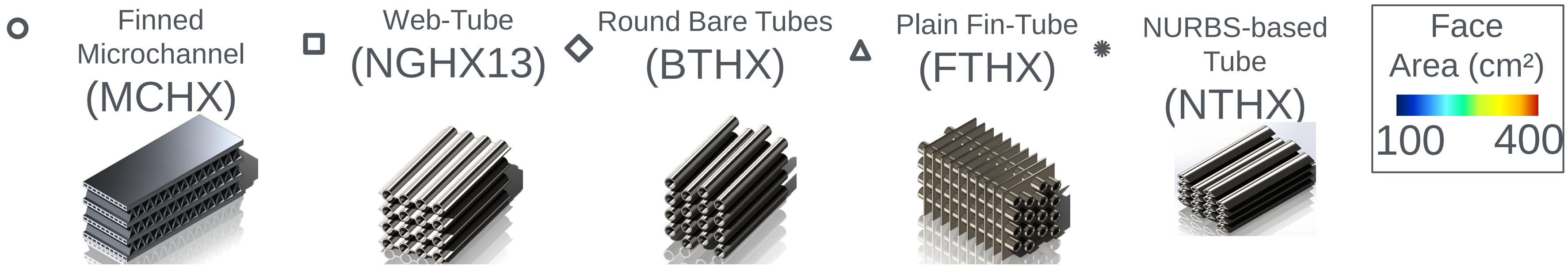
Progress and Accomplishments

- Analyzed 8+ heat exchanger geometries
- Developed a new methodology for optimizing tube shapes – no longer constrained by circular/rectangular tubes
- Fabricated and tested three 1kW prototypes
  - Measured data agree within 10% of predicted performance
- Wind tunnel facility at UMD now online
- Work in progress
  - Design and prototyping of 10kW (nominal 3TR) heat exchangers
  - System-test facility is being developed, equipment donated by sponsors of UMD-CEEE Consortium

Accomplishments

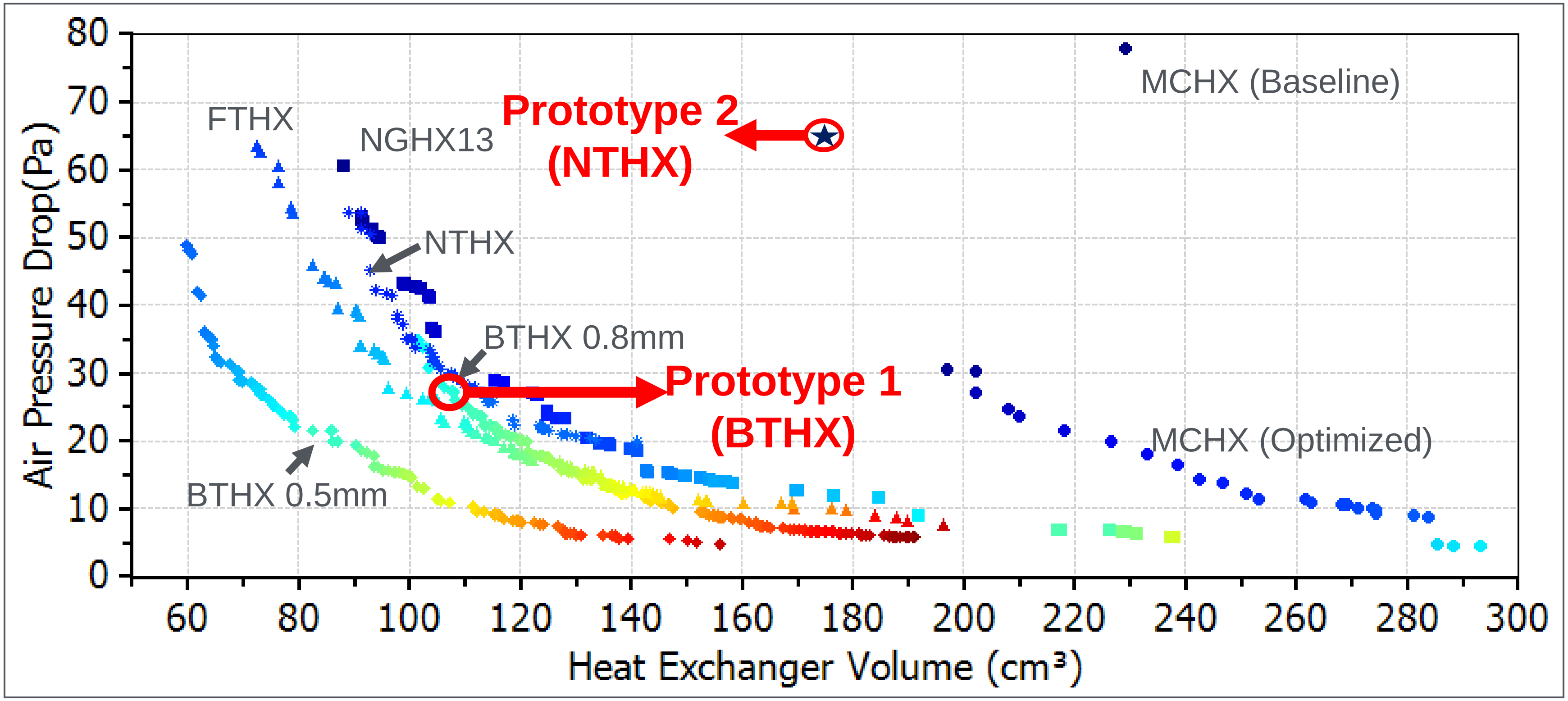
Fixed flow rates; ΔT=50K(MCHX / NGHX13); ΔT=42K (BTHX / FTHX); ΔT=40K (NTHX)

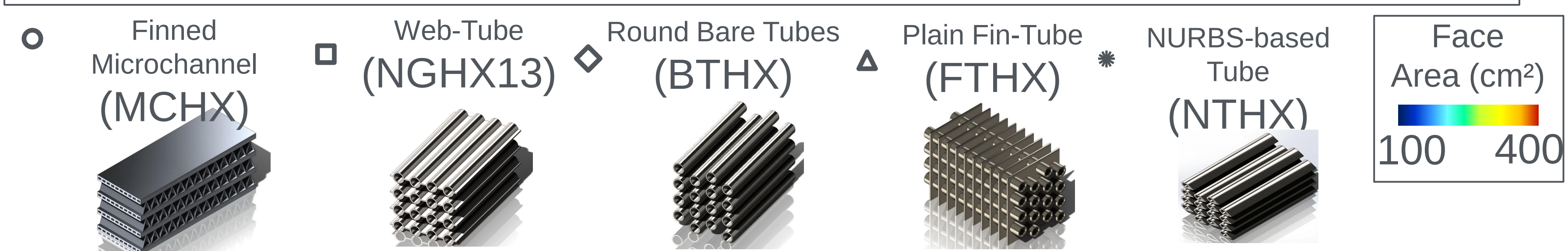




Accomplishments (non-Animated)

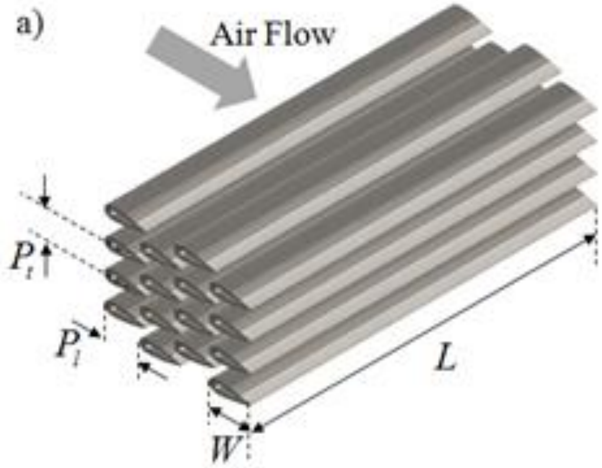
Fixed flow rates; ΔT=50K(MCHX / NGHX13); ΔT=42K (BTHX / FTHX); ΔT=40K (NTHX)

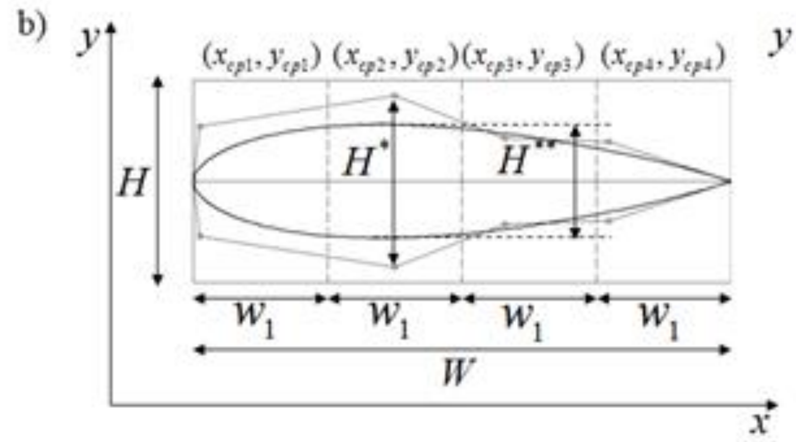


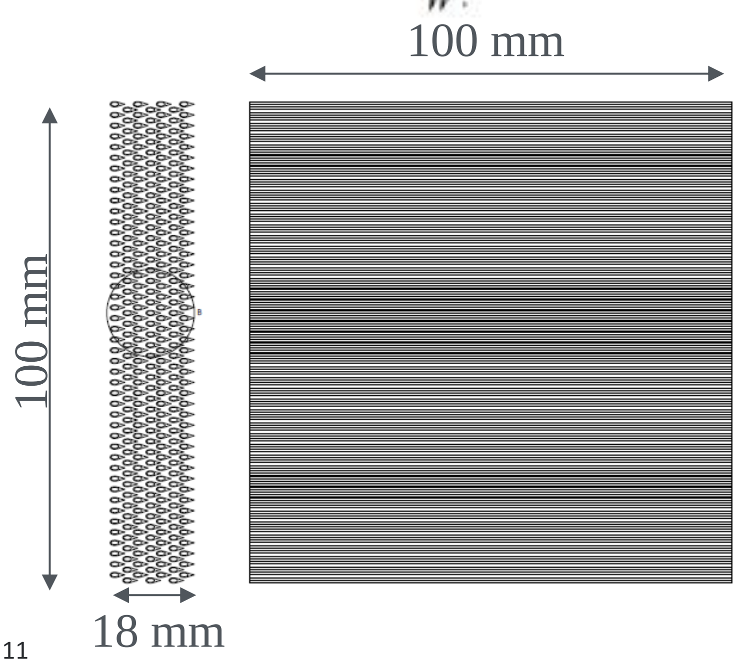


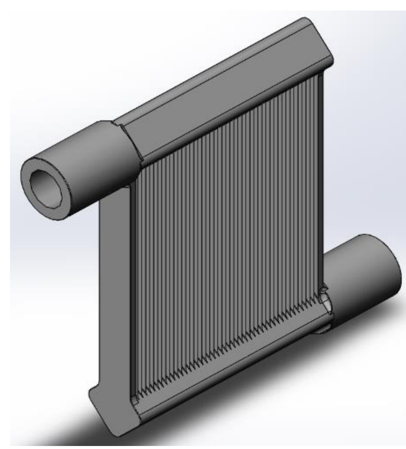
Progress and Accomplishments

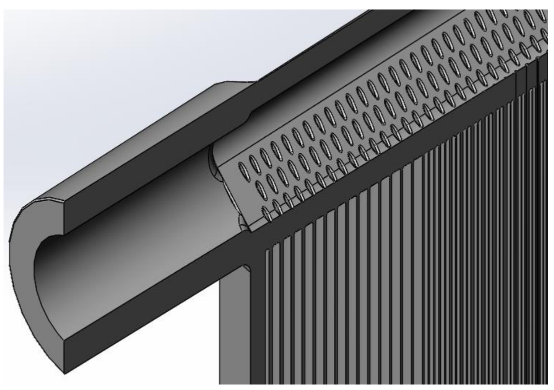
- Novel multi-scale approach for tube shape optimization



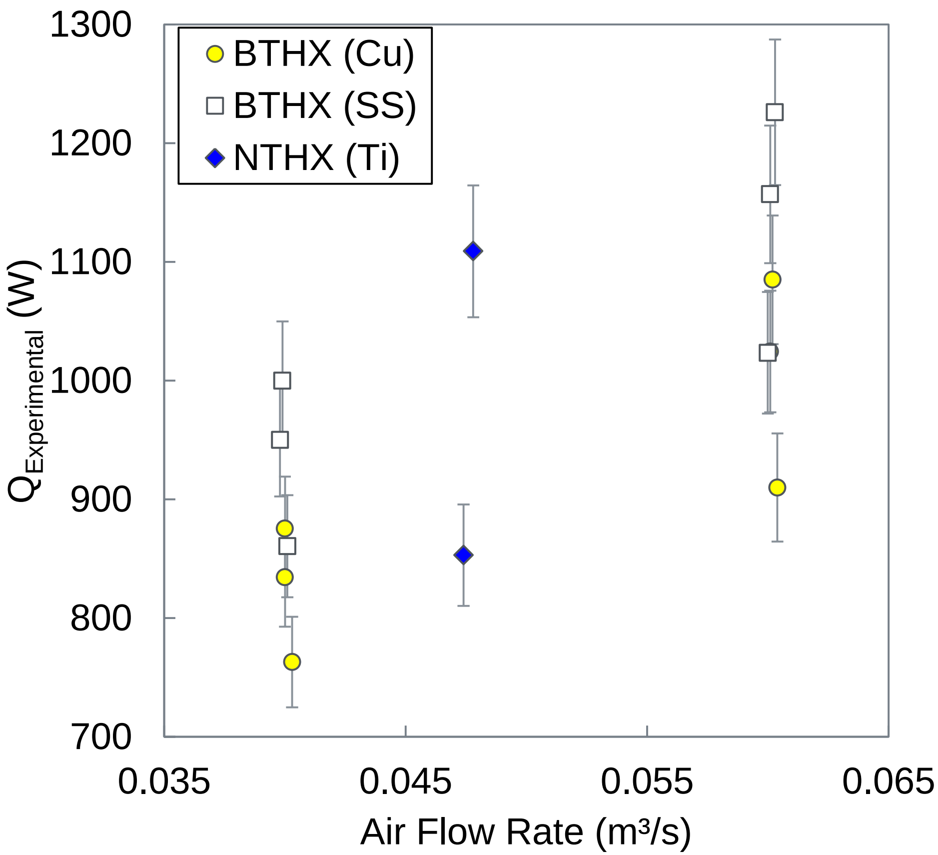


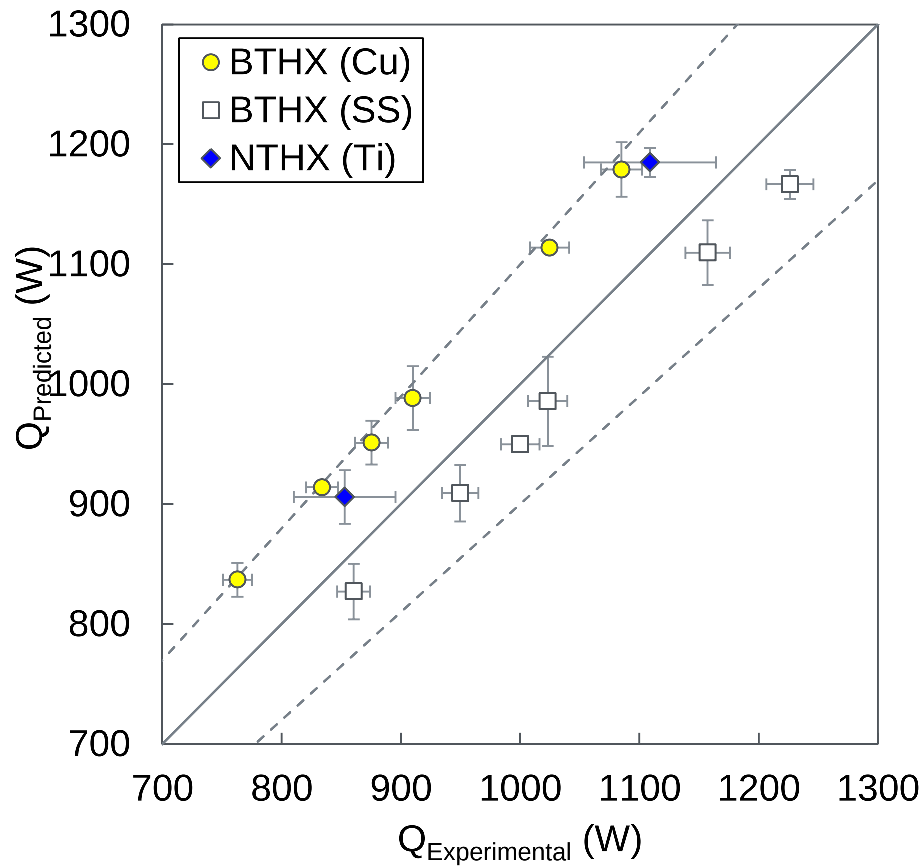






Accomplishments: Measured Capacity





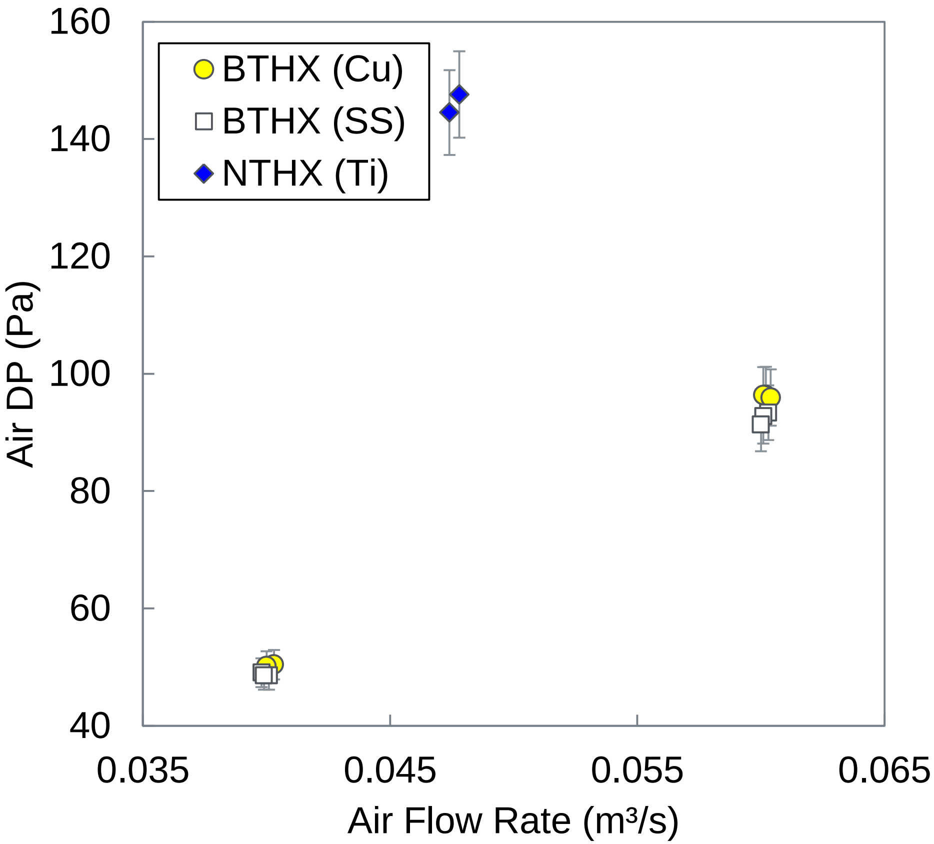
Round Bare Tubes (BTHX)

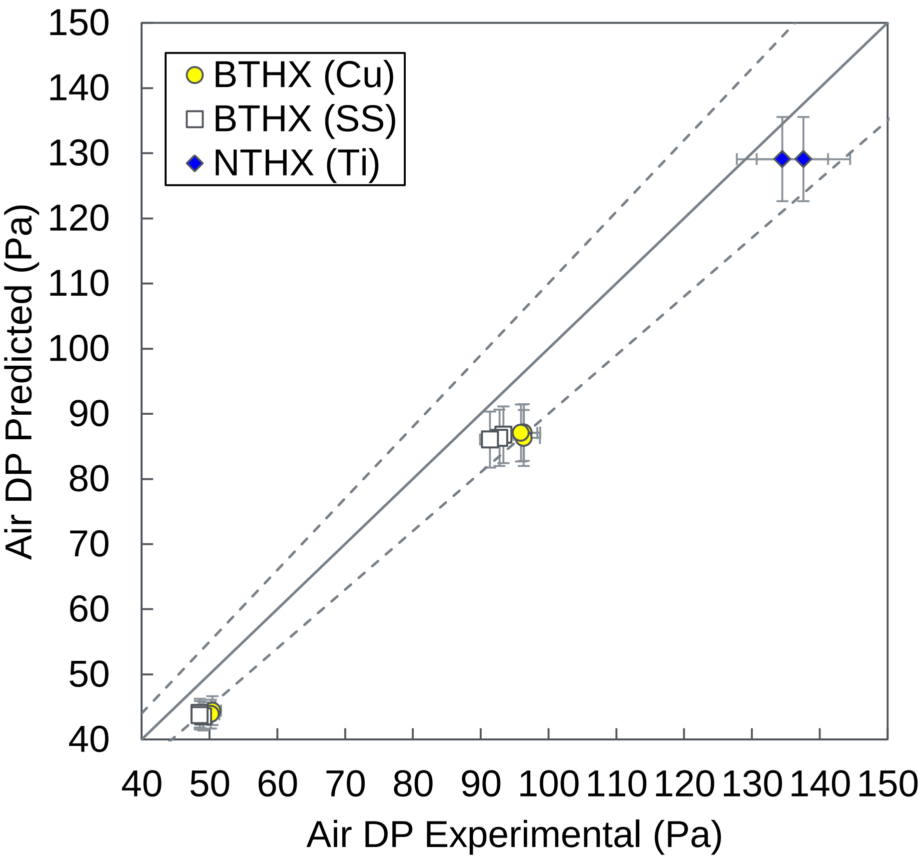
NURBS-based Tube (NTHX)

Causes for Deviation:

Air by pass; Measurement uncertainty; Un even tube spacing

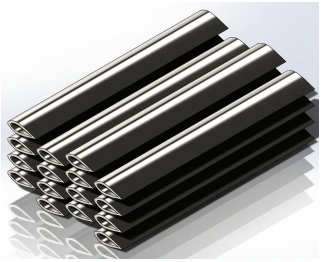
Accomplishments: Measured Performance





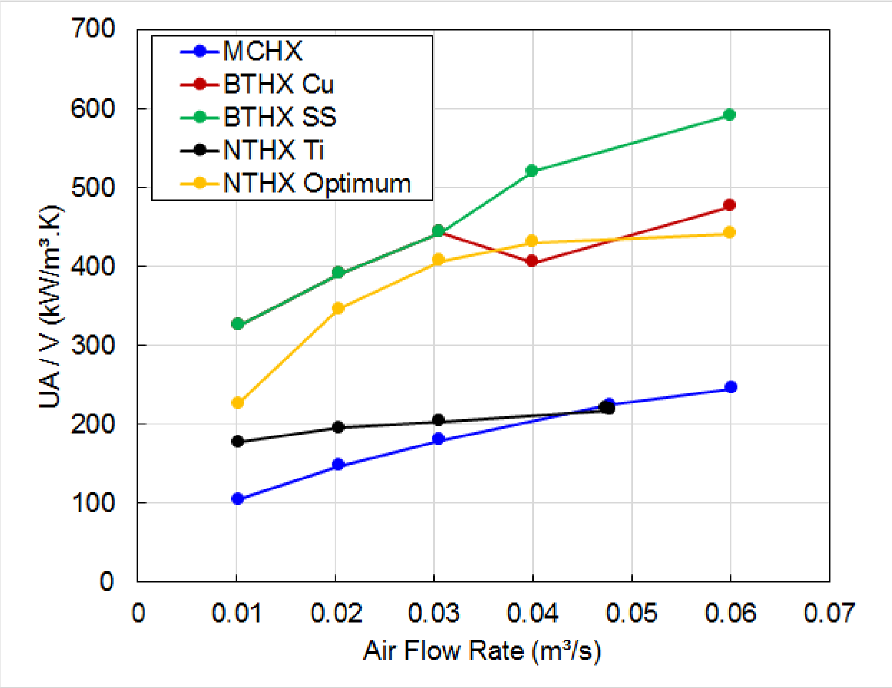
Round Bare Tubes (BTHX)

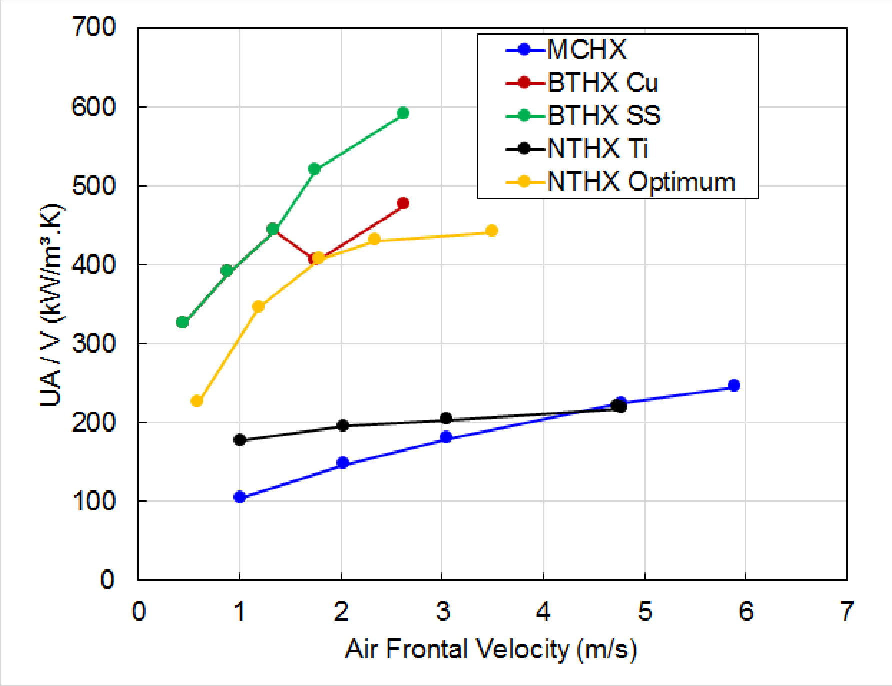
NURBS-based Tube (NTHX)



U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Accomplishments: Performance Comparison

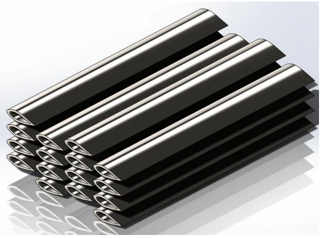




Finned Microchannel (MCHX)

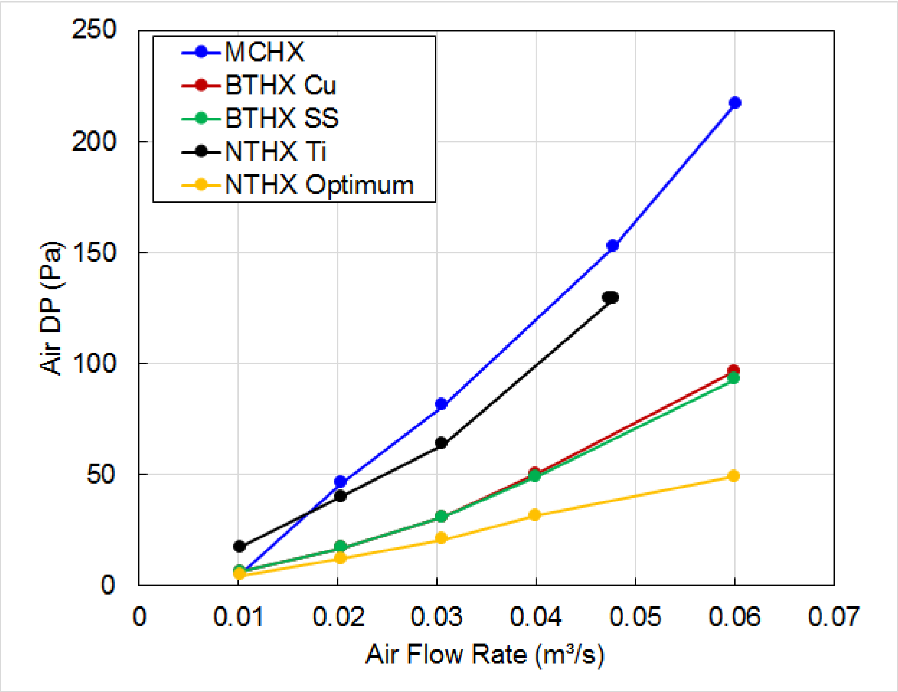
Round Bare Tubes (BTHX)

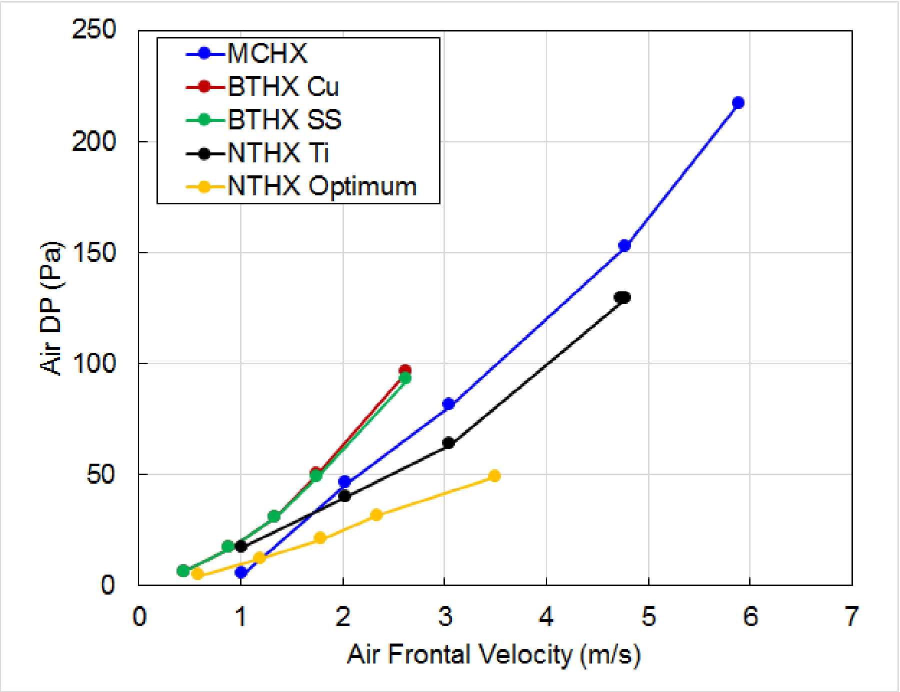
NURBS-based Tubes (NTHX)



U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Accomplishments: Performance Comparison

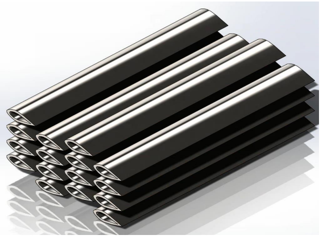




Finned Microchannel (MCHX)

Round Bare Tubes (BTHX)

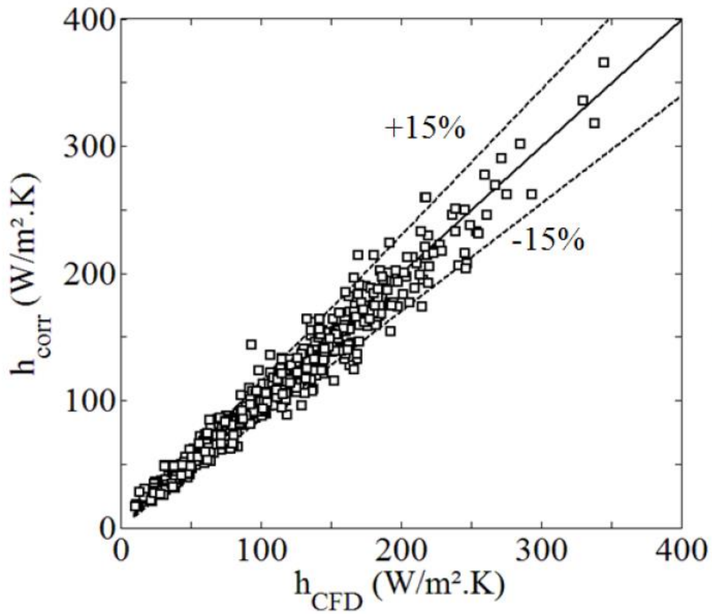
NURBS-based Tubes (NTHX)

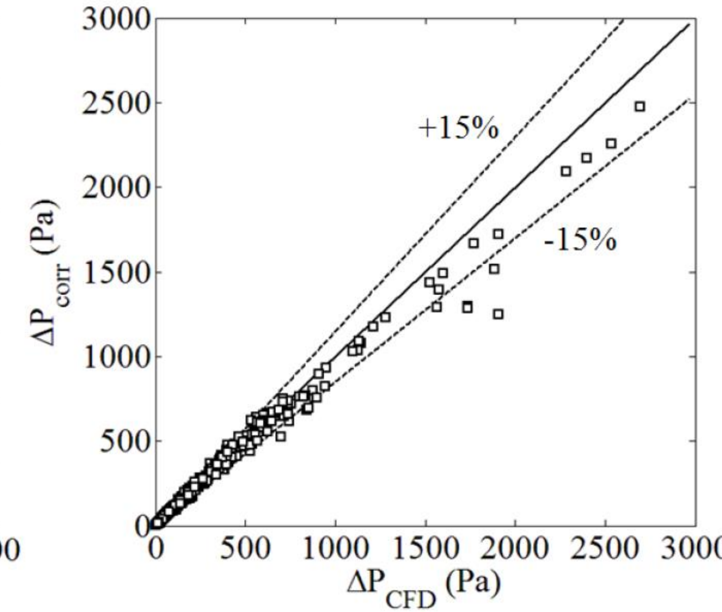


Accomplishments: Design tools for industry

- Air-side performance correlations for:

- Bare tubes
- Plain Fins
- Wavy Fins





Heat Exchanger	Fin and Tube	
Air side performance metrics	h_{air}	ΔP_{air}
10% absolute deviation	63.58%	79.52%
15% absolute deviation	82.49%	93.17%
20% absolute deviation	91.55%	95.98%
30% absolute deviation	96.98%	98.39%
Absolute relative mean deviation	9.51%	6.40%
Mean GCI[21]	4.20%	4.30%
Coefficient of determination (R^2)	95.67%	98.53%

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Project Integration and Collaboration

Project Integration

- Collaboration with key project partners to identify and solve manufacturing and deployment challenges
- Collaboration with ORNL for performance testing
- First-hand feedback from industry partners of UMD Consortium

Partners, Subcontractors, and Collaborators

- ORNL: Subcontractor; design, advanced manufacturing and testing
  - Omar Abdelaziz: Group Leader, PI; Patrick Geoghegan: Scientist
- Luvata: Industry partner; manufacturing, system integration and marketing
  - Mike Heidenreich: VP of Product Engg; Russ Cude: Director of Engg., Americans; Randy Weaver: R&D Engineer
- ICA / Heat Transfer Technologies: Industry partner; heat exchanger manufacturing process development
  - Yoram Shabtay: President; John Black: VP of Market Development
- Wieland: Industry Partner; tube manufacturer
  - Steffen Rieger, Technical Marketing Manager
- Burr Oak Tool Inc.: Specializing in machines, tools and services for HX mfg. Roger Tetzloff, Innovations Manager

Project Communications

Kick-off Meeting:

- Kick-off Meeting & Brainstorming Workshop, 22-Apr-2013, University of Maryland
- Semi-annual in-person progress review meetings (Mar and Sep), every year

IP: Provisional patent application in progress

Publications (2014 – 4, 2015 – 3)

1. Bacellar, D., Ling, J., Abdelaziz, O., Aute, V., Radermacher, R., **Design of Novel Air-to-Refrigerant Heat Exchangers Using Approximation Assisted Optimization**, ASME 2014 Verification & Validation Symposium, May 7-9, 2014 – Las Vegas, Nevada.
2. Bacellar, D., Aute, V., Radermacher, R., **CFD-Based Correlation Development for Air Side Performance of Finned and Finless Tube Heat Exchangers with Small Diameter Tubes**, 15th International Refrigeration and Air Conditioning Conference at Purdue, July 14-17, 2014.
3. Bacellar, D., Ling, J., Abdelaziz, O., Aute, V., Radermacher, R., **Multi-scale modeling and approximation assisted optimization of bare tube heat exchangers**, Proceedings of the 15th International Heat Transfer Conference, IHTC-15, August 10-15, 2014, Kyoto, Japan.
4. Saleh, K., Bacellar, D., Aute, V., Radermacher, R., **An Adaptive Multiscale Approximation Assisted Multiobjective Optimization Applied to Compact Heat Exchangers**, 4th International Conference on Engineering Optimization, EngOpt 2014, September 8-11, Lisbon, Portugal.
5. Bacellar, D., Abdelaziz, O., Aute, V., Radermacher, R., **Novel Heat Exchanger Design using Computational Fluid Dynamics and Approximation Assisted Optimization**, ASHRAE 2015, Winter Conference, January 24-28, 2015 - Chicago, IL.
6. Bacellar, D., Aute, V., Radermacher, R., **A Method for Air-To-Refrigerant Heat Exchanger Multi-Scale Analysis and Optimization with Tube Shape Parameterization**, 24th IIR International Congress of Refrigeration, August 16 – 22, 2015 – Yokohama, Japan. **(MANUSCRIPT SUBMITTED)**
7. Bacellar, D., Aute, V., Radermacher, R., **CFD-Based Correlation Development for Air Side Performance on Finned Tube Heat Exchangers with Wavy Fins and Small Tube Diameters**, 24th IIR International Congress of Refrigeration, August 16 – 22, 2015 – Yokohama, Japan. **(MANUSCRIPT SUBMITTED)**

Next Steps and Future Plans

- Conduct air-side performance measurements (in progress)
- Design and fabricate 10kW Radiators (in progress)
- Test radiators and update models as required
  - Conduct noise/vibrations analysis
- Design and fabricate evaporators and condensers for 3 Ton system (in-progress)
- Test evaporators and condensers in wind tunnel
- System Testing
  - Set up system test facility (HP system acquisition in progress)
  - Test evaporators and condensers as a part of complete system
- Develop and disseminate tools for heat exchanger analyses (12/30/2015)
- Develop and disseminate manufacturing guidelines and lessons learned (1/30/2016)

REFERENCE SLIDES

Project Budget

Project Budget: DOE Total $1050K, FY13-17 (3/1/2013 to 2/29/2016)
Variances: No change in overall budget; Higher spending in Year-2, due to prototype fabrication and test facility setup
Cost to Date: $881K
Additional Funding: No additional funding for DOE is expected. Various in-kind contribution from industry partners

Budget History					
FY2013 – FY2014 (past)		FY2015 (current)		FY2016 (planned)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$751	NA	$130K	NA	$169K	NA

Project Plan and Schedule

Project Schedule

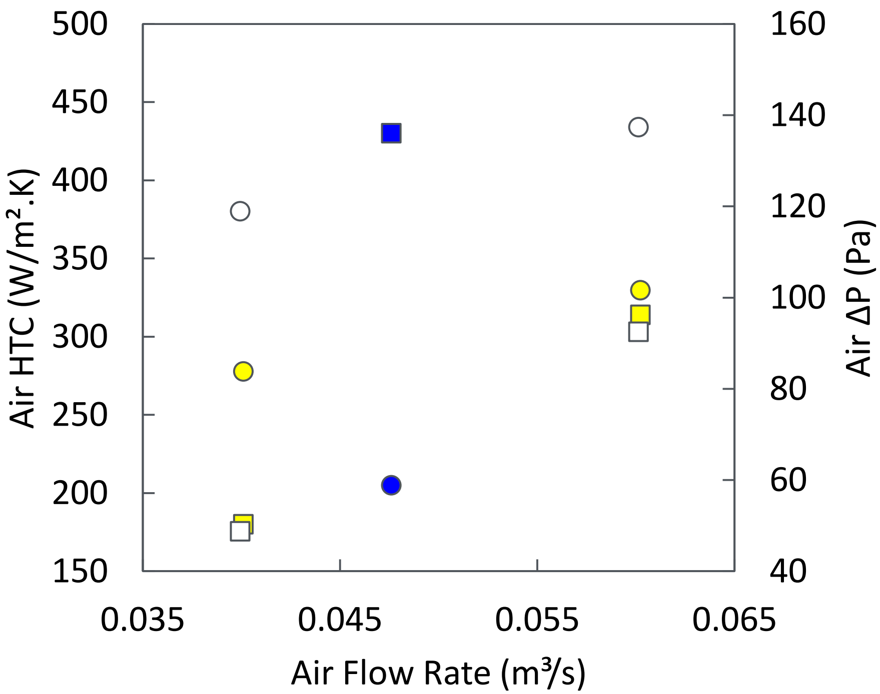
Project Start: 03/01/2013

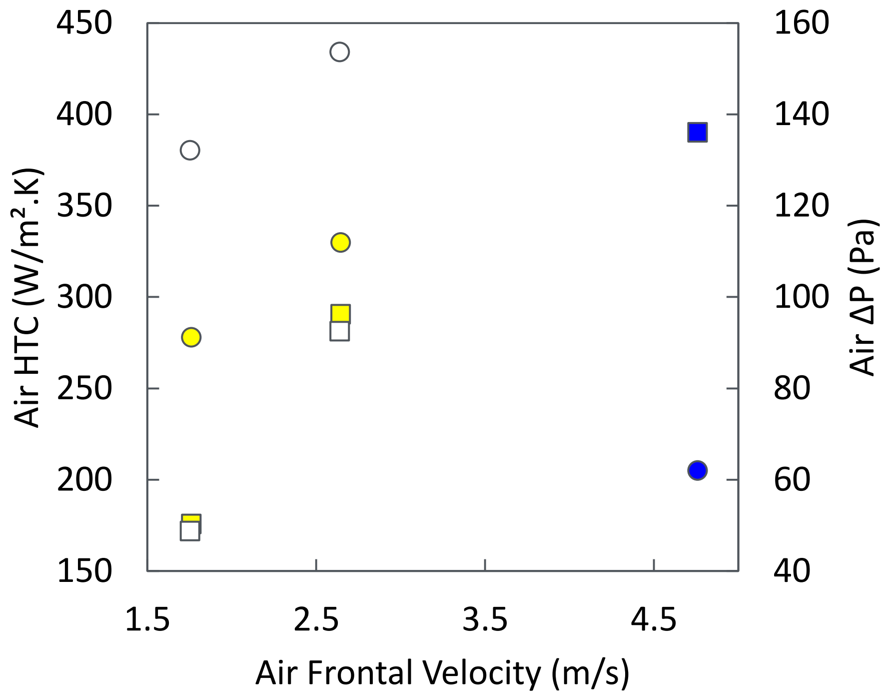
Projected End: 02/29/2016

(light blue)	Completed Work
(dark blue)	Active Task (in progress work)
◆ (red)	Milestone/Deliverable (Originally Planned)
◆	Milestone/Deliverable (Actual)

Task	FY2013 Q1 (Oct-Dec)	FY2013 Q2 (Jan-Mar)	FY2013 Q3 (Apr-Jun)	FY2013 Q4 (Jul-Sep)	FY2014 Q1 (Oct-Dec)	FY2014 Q2 (Jan-Mar)	FY2014 Q3 (Apr-Jun)	FY2014 Q4 (Jul-Sep)	FY2015 Q1 (Oct-Dec)	FY2015 Q2 (Jan-Mar)	FY2015 Q3 (Apr-Jun)	FY2015 Q4 (Jul-Sep)	FY2016 Q1 (Oct-Dec)	FY2016 Q2 (Jan-Mar)	FY2016 Q3 (Apr-Jun)	FY2016 Q4 (Jul-Sep)
Past Work																
Project kick-off		◆														
Finalize best designs for various materials						◆										
Manufacture sample tubes, headers and investigate joining options						◆										
Select most promising materials and techniques						◆										
Identify preferred design andmanufacturing methods						◆										
Current/Future Work																
Complete pressure tests on prototype heat exchangers							◆									
Commission the air-side test facility							◆									
Fabricate multiple (radiator and condenser) 1 kW prototypes for testing							◆									
Test of 1kW Heat Exchangers								◆								
Analyze system level performance benefits								◆								
Improve designs and propose optimal designs for 10 kW capacity									◆							
Analyze system performance of 10kW designs for diff. applications										◆						
Fabricate 10 kW capacity prototypes for testing											◆					
Test 10 kW propotype												◆				
Develop and disseminate tools for heat exchanger analyses													◆			
Develop and disseminate manufacturing guidelines for miniature heat exchangers														◆		
Closure														◆		

Accomplishments: Measured Performance





Symbol Type: ○ Air HTC □ Air ΔP

Symbol Color: BTHX (Cu) BTHX (SS) NTHX (Ti)

Round Bare Tubes (BTHX)

NURBS Shap Tubes (NTHX)