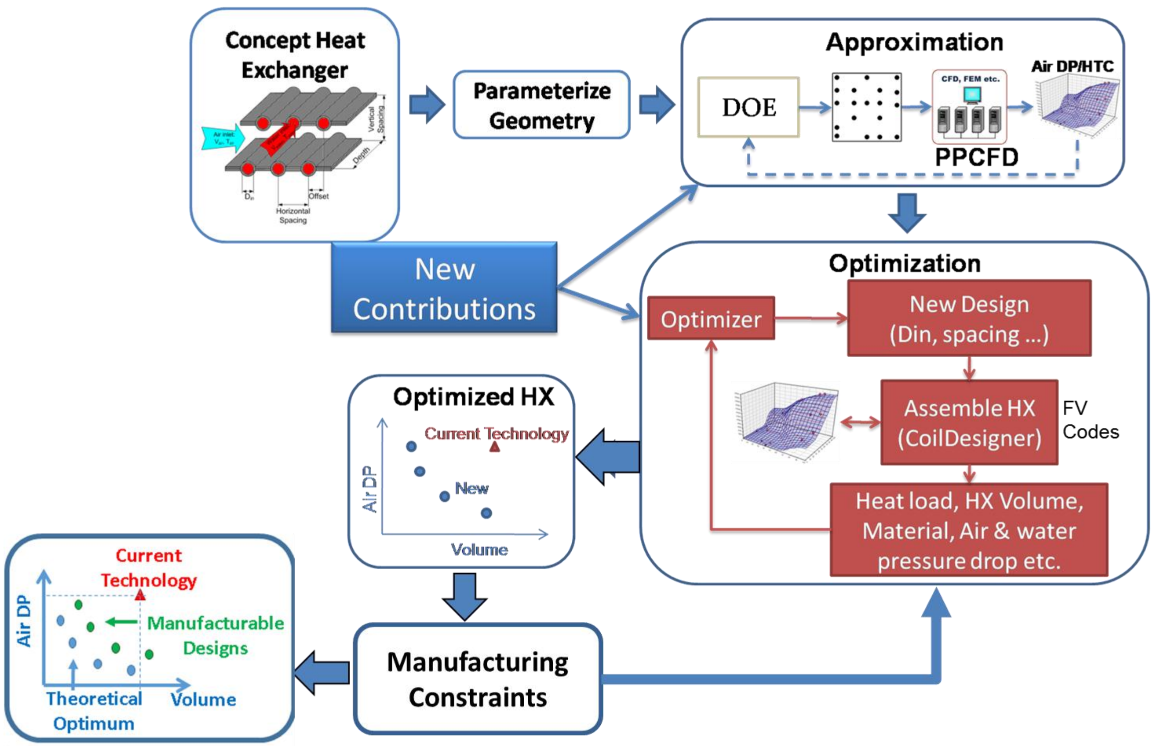
Miniaturized Air-to-Refrigerant Heat Exchangers

2014 Building Technologies Office Peer Review



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

Project Summary

Timeline:

Start date: 03/01/2013

Planned end date: 02/29/2016

Key Milestones

1. Heat exchanger designs/process: 6/30/14
2. Fabrication/testing of 1 kW: 9/30/14
3. Fabrication/testing of 10 kW: 9/30/2015

Budget:

Total DOE $ to date: $561K

Total future DOE $: $489K

Target Market/Audience:

Residential and commercial heat pump systems with various capacity scales

Condensers as first choice of application

Key Partners:

Oak Ridge National Laboratory

Luvata

International Copper Association

Wieland

Heat Transfer Technologies

Project Goal:

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

Performance Target: Miniaturized air-to-refrigerant heat exchanger with at least 20% less volume, 20% less material and 20% more performance than current designs.

Market Target: To be in production within five years.

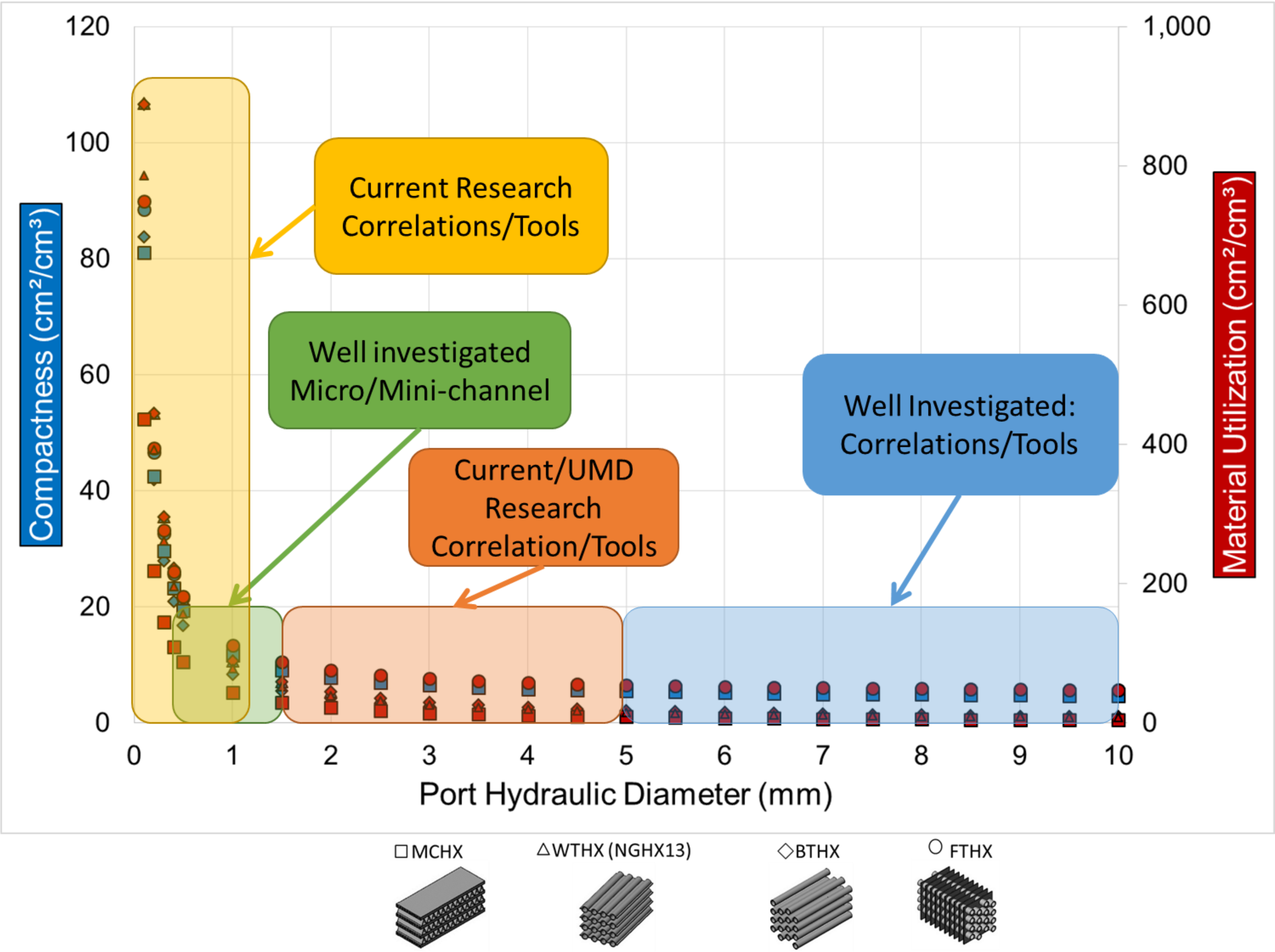
Purpose and Objectives

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: 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
- Manufacturing guidelines to facilitate production within 5 years

Future of Heat Exchangers



Approach

- Develop a comprehensive multi-scale modeling and optimization approach for design optimization of novel heat exchangers
  - Parallel Parameterized CFD
  - Approximation Assisted Optimization
- Develop 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 system level performance of novel heat exchangers
  - Evaporator and condenser of a system based on same design

Approach : Key Issues

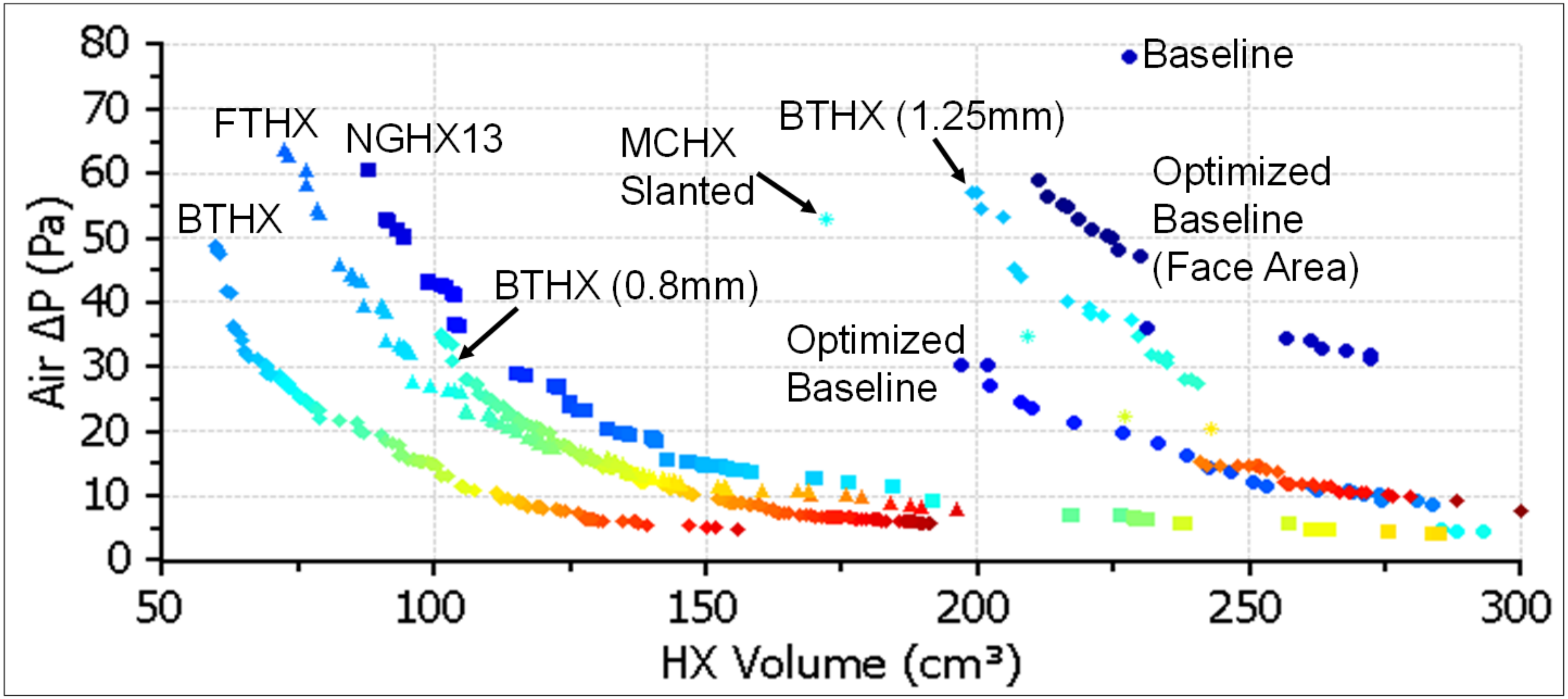
- Lack of basic heat transfer and fluid flow data for design and analyses of air-to-refrigerant heat exchangers with small flow channels
- Availability for small diameter tubes
- Joining/manufacturing challenges
- Face area constraints
- Fouling and flow mal-distribution
- Wetting

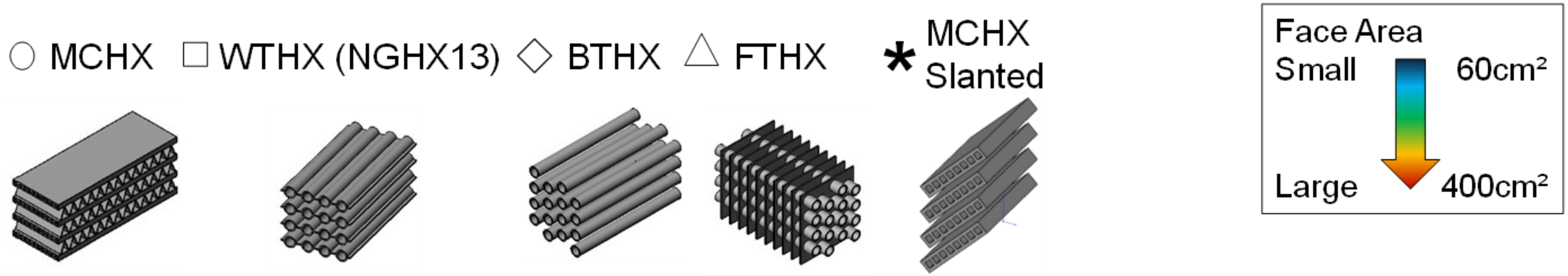
Approach : Distinctive Characteristics

- Develop 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 development is in progress, with target production within 5 years

Progress and Accomplishments : Analyses

- Identified 9 candidate geometries
- Developed analyses codes, conducted design optimization for 1 kW radiators

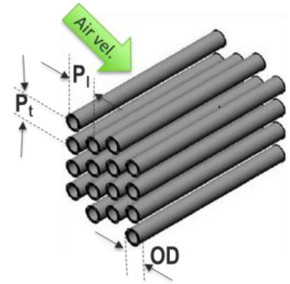


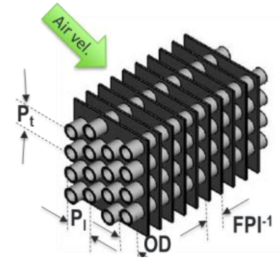


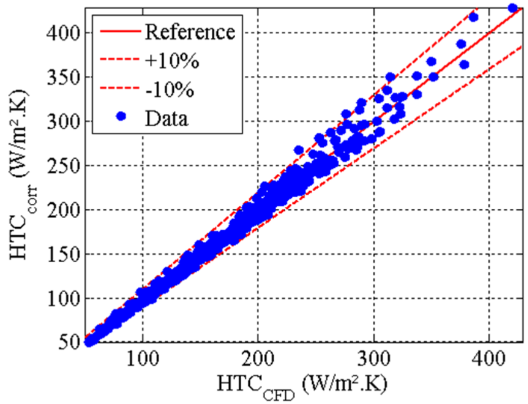
Project Accomplishments: New Correlations

Bare Tube Heat Exchanger

Design Variable	unit	Range
OD	mm	2.0 to 5.0
P_t ratio (OD)	-	1.5 to 3.0
P_l ratio (OD)	-	1.5 to 3.0
N_t (Bank of tubes)	-	2 to 20
Air velocity	m/s	0.5 to 7.0

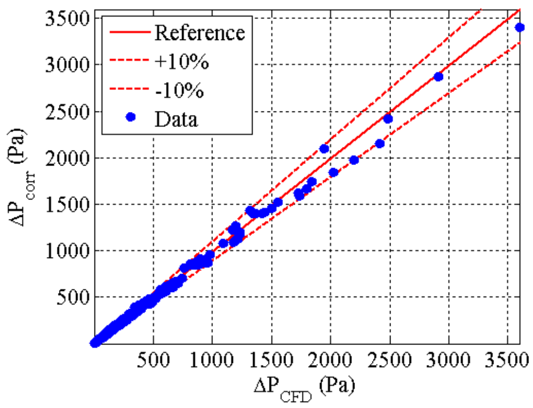






Plain Fin and Tube Heat Exchanger

Design Variable	unit	Range
OD	mm	2.0 to 5.0
P_t ratio (OD)	-	1.5 to 3.0
P_l ratio (OD)	-	1.5 to 3.0
N_t (Bank of tubes)	-	2 to 10
FPI	in^{-1}	8 to 24
Air velocity	m/s	0.5 to 7.0



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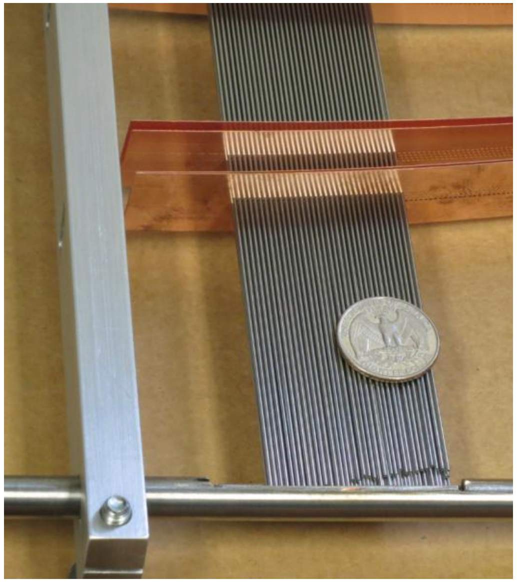
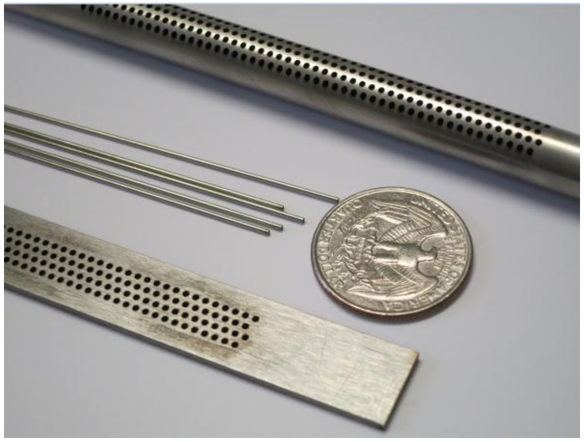
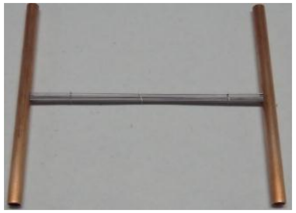
Progress and Accomplishments

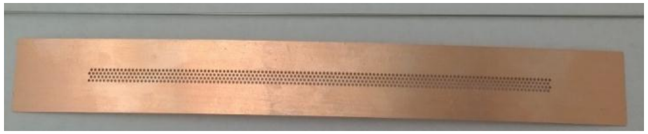
Accomplishments:

- Manufacturing
  - Investigated commercially available tubes
  - Investigated conventional manufacturing options
  - Investigating additive manufacturing options
  - Fabricating prototype heat exchangers









Progress and Accomplishments

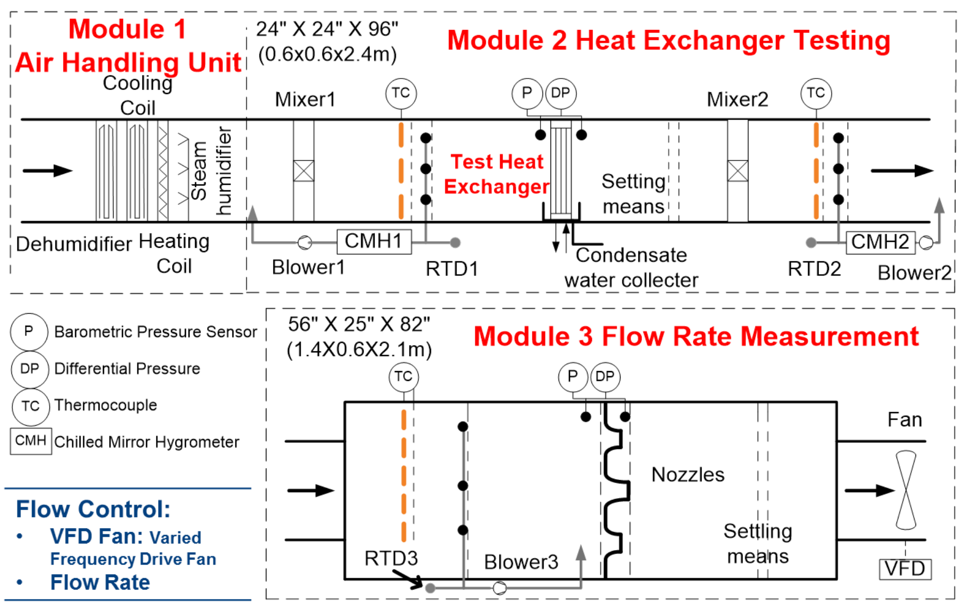
Accomplishments: Performance Testing

- Designed and fabricating a test facility

Project Contribution to Energy Efficiency :

- Comparison of predicted air-side performance to existing data shows a 22% deviation ➔ Better agreement is expected with new test facility and larger heat exchangers
- Additional performance measurements to be carried out in 2014

Awards/Recognition: None



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Project Integration and Collaboration

Project Integration:

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

Partners, Subcontractors, and Collaborators:

- ORNL: Subcontractor; design, advanced manufacturing and testing
  - Omar Abdelaziz: Scientist, PI
  - Patrick Geoghegan: Scientist
- Luvata: Industry partner; manufacturing, system integration and marketing
  - Mike Heidenreich: VP of Product Engineering
  - Randy Weaver: Modeling Engineer
- Heat Transfer Technologies: Industry partner; heat exchanger design, manufacturing process development
  - Yoram Shabtay: President
  - John Black: VP of Market Development

Project Communications

Kick-off Meeting:

- Kick-off Meeting & Brainstorming Workshop, 22-Apr-2013, University of Maryland

Publications:

- Bacellar D., Abdelaziz O., Aute V., Radermacher, R., 2014, Design of Novel Air-to-Refrigerant Heat Exchangers Using Approximation Assisted Optimization, ASME Verification & Validation Symposium, May 7-9, 2014. ***Accepted for publication***.

- Bacellar D., Ling J., Aute V., Radermacher, R., Abdelaziz, O., 2014, Multi-Scale Modeling and Approximation Assisted Optimization of Bare Tube Heat Exchangers, Proceedings of the International Heat Transfer Conference, IHTC-15, Aug 10-15, 2014, Kyoto, Japan. ***Accepted for publication***.

- Bacellar D., Ling J., Aute V., Radermacher, R.,2014, CFD-based Correlation Development for Air-Side Performance for finned and finless tube heat exchangers for small tube diameters, 2014 International Refrigeration and Air-Conditioning Conference at Purdue, July 14-17, 2014, Purdue, IN. ***Abstract Accepted***.

Next Steps and Future Plans

Next Steps and Future Plans:

- Complete prototype fabrication
- Conduct pressure tests on prototype heat exchangers
- Commission the test facility (5/30/3014)
- Fabricate multiple (radiator and condenser) 1 kW prototypes for testing (6/30/2014)
- Test 1kW heat exchangers (9/30/2014)
- Improve designs and propose optimal designs for 10 kW capacity (1/30/2015)
- Fabricate 10 kW capacity prototypes for testing (6/30/2015)
- Develop and disseminate tools for heat exchanger analyses (12/30/2015)
- Develop and disseminate manufacturing guidelines for miniature heat exchangers (1/30/2016)

REFERENCE SLIDES

Project Budget

Project Budget: DOE Total $1,050K , FY12-16 (3/1/2013 to 2/29/2016)
Variances: No variances at present
Cost to Date: $561K
Additional Funding: No additional funding is expected.

Budget History					
FY2012-FY2013 (past)		FY2014 (current)		FY2015 – FY2016 (planned)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$504K	NA	$57K	NA	$489K	NA

Project Plan and Schedule

Project Schedule		
Project Start: 03/01/2013	(light blue)	Completed Work
Projected End: 02/29/2016	(dark blue)	Active Task (in progress work)
	◆ (red)	Milestone/Deliverable (Originally Planned)
	◆	Milestone/Deliverable (Actual)

	FY2013				FY2014				FY2015				FY2016			
Task	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)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	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														◆		