Miniaturized Air-to-Refrigerant Heat Exchangers

2015 Building Technologies Office Peer Review

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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

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/Audience:
Residential and commercial heat pump systems with various capacity scales.
Condenser as first choice of application
**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

- Current Research Correlations/Tools
- Well investigated Micro/Mini-channel
- Current/UMD Research Correlation/Tools
- Well Investigated: Correlations/Tools

- MCHX
- WTHX (NGHX13)
- BTHX
- FTHX
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
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-CEEIn Consortium
Accomplishments

Fixed flow rates; $\Delta T=50K$ (MCHX / NGHX13); $\Delta T=42K$ (BTHX / FTHX); $\Delta T=40K$ (NTHX)

Prototype 1
(BTHX)

Prototype 2
(NTHX)

Finned Microchannel
(MCHX)

Web-Tube
(NGHX13)

Round Bare Tubes
(BTHX)

Plain Fin-Tube
(FTHX)

NURBS-based Tube
(NTHX)

Face Area (cm²)

100 400
Accomplishments (non-Animated)

Fixed flow rates; \( \Delta T=50K (MCHX / NGHX13); \Delta T=42K (BTHX / FTHX); \Delta T=40K (NTHX) \)
Progress and Accomplishments

- Novel multi-scale approach for tube shape optimization
Accomplishments: Measured Capacity

Causes for Deviation:
Air by pass; Measurement uncertainty; Uneven tube spacing

Round Bare Tubes (BTHX)

NURBS-based Tube (NTHX)
Accomplishments: Measured Performance

- **Air Flow Rate (m³/s)**: 0.035, 0.045, 0.055, 0.065
- **Air DP Predicted (Pa)**: 40, 50, 60, 70, 80, 90, 100, 110, 120, 130, 140, 150
- **Air DP Experimental (Pa)**: 40, 50, 60, 70, 80, 90, 100, 110, 120, 130, 140, 150

- **Materials**: BTHX (Cu), BTHX (SS), NTHX (Ti)

- **Round Bare Tubes (BTHX)**
- **NURBS-based Tube (NTHX)**
Accomplishments: Performance Comparison

Finned Microchannel (MCHX)  Round Bare Tubes (BTHX)  NURBS-based Tubes (NTHX)
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

<table>
<thead>
<tr>
<th>Heat Exchanger</th>
<th>Fin and Tube</th>
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<tbody>
<tr>
<td>Air side performance metrics</td>
<td>$h_{\text{air}}$</td>
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<tr>
<td>10% absolute deviation</td>
<td>63.58%</td>
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<tr>
<td>15% absolute deviation</td>
<td>82.49%</td>
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<td>20% absolute deviation</td>
<td>91.55%</td>
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<td>30% absolute deviation</td>
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<td>Absolute relative mean deviation</td>
<td>9.51%</td>
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<td>Mean GCT$^{21}$</td>
<td>4.20%</td>
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<td>Coefficient of determination ($R^2$)</td>
<td>95.67%</td>
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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 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

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:** 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

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<th>FY2015 (current)</th>
<th>FY2016 (planned)</th>
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<tr>
<td>DOE Cost-share</td>
<td>$751  NA</td>
<td>$130K NA</td>
<td>$169K NA</td>
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## Project Plan and Schedule

### Project Schedule

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<th>FY2015</th>
<th>FY2016</th>
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<td>Projected End: 02/29/2016</td>
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<td>Completed Work</td>
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<td>Active Task (in progress work)</td>
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<td>◆ Milestone/Deliverable (Originally Planned)</td>
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<td>◆ Milestone/Deliverable (Actual)</td>
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### 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 and manufacturing 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 prototype
- Develop and disseminate tools for heat exchanger analyses
- Develop and disseminate manufacturing guidelines for miniature heat exchangers
- Closure
Accomplishments: Measured Performance

Symbol Type: Symbol Color:
- □ Air HTC
- ○ Air ΔP
- - BTHX (Cu)
- - BTHX (SS)
- - NTHX (Ti)

Round Bare Tubes (BTHX)  
NURBS Shap Tubes (NTHX)