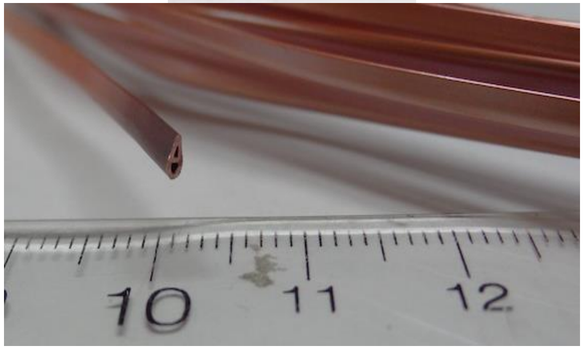
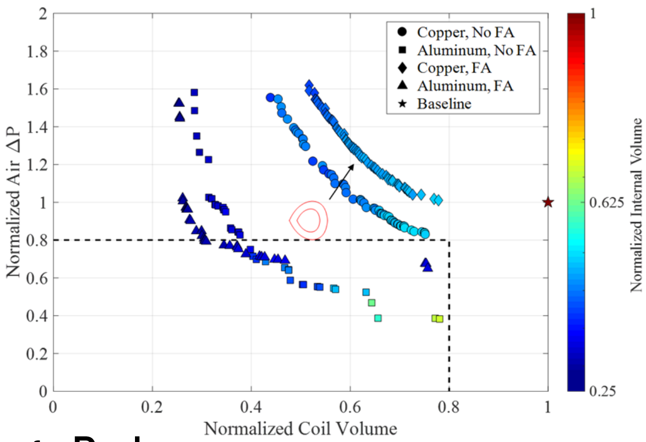
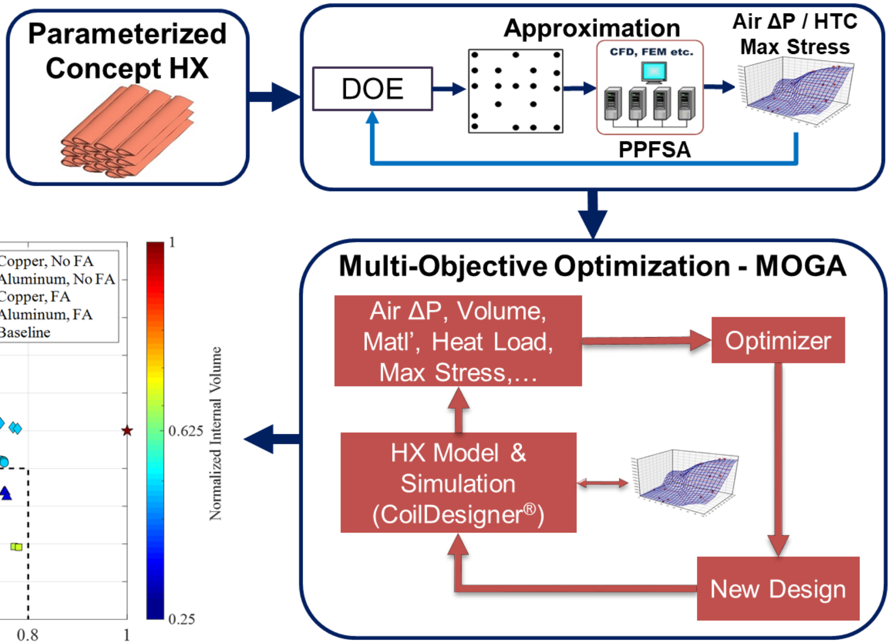
U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

Design and Manufacturing of High Performance, Reduced Charge Heat Exchangers (HPRC-HX)







MOGA = Multi-Objective Genetic Algorithm
PPFSA = Parallel Parameterized Fluid & Structural Analysis

University of Maryland College Park

Prof. Reinhard Radermacher

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Project Summary

Timeline:

Start date: February, 2018

Planned end date: February, 2021

Key Milestones

1. Non-round tube optimization and manufacturability investigation; Mar 2019
2. Develop, fabricate and test prototype HXs; March 2020/2021

Budget:

Total Project $ to Date:

- DOE: $231,323
- Cost Share: $353,627

Total Project $:

- DOE: $1,075,000
- Cost Share: $1,250,000

Key Partners:

ORNL (Funded)	Arconic
HTT (Funded)	Daikin/Goodman
Wieland	JCI
Burr Oak	ICA
Luvata/Modine	Brazeway
Guentner	3D Systems

Project Outcome:

- Development of a comprehensive HX optimization framework
- Accelerate R&D of novel HX designs promoting 25% reduction in size and weight while maintaining structural integrity & thermal performance
- Facilitate closure of the technology-to-market gap for non-round tube HXs

Project Team

- **University of Maryland, College Park (UMD, Lead)**
  - Reinhard Radermacher (PI); Vikrant Aute (Co-PI); Yunho Hwang (Co-PI); Jiazhen Ling; Jan Muehlbauer
  - Graduate Research Assistants: Ellery Klein; James Tancabel
  - ***Expertise*:** 30+ years of experience in R&D of heat pumps, refrigerant, HVAC&R components and systems, modeling and optimization software development; system and component test facilities; industry- and government-funded research collaborations

- **Oak Ridge National Laboratory (ORNL)**
  - *Patrick J. Geoghegan* (Co-PI); *Ayyoub Mehdizadeh Momen*; *Mingkan Zhang*
  - ***Expertise*:** Computational heat transfer; additive manufacturing; testing

- **Heat Transfer Technologies LLC. (HTT)**
  - *Yoram Shabtay* (Co-PI, President); *John Black* (VP, Market Development)
  - ***Expertise*:** 20+ years of experience in design and manufacturing of heat exchangers for pre-production evaluation; development of innovative joining techniques for small diameter tubes and manifolds

Industry Partners

- **3D Systems**
  - Severine Guevara
- **Arconic**
  - Ming Li; Tao Zhou; Harry R. Zonker
- **Brazeway**
  - Scot Reagen
- **Burr Oak Tool**
  - Sean Peterson; Rocky Smith
- **Goodman Manufacturing**
  - James Kistler; Khaled H. Saleh
- **Güntner**
  - Stanislav Perencevic
- **International Copper Association**
  - Hal Stillman
- **JCI**
  - Roy Crawford; Avi Gholap
- **Luvata / Modine**
  - Russ Cude; Michael E. Heidenreich
- **Wieland**
  - Michael Schuster; Dr. Christoph Walther

Challenge

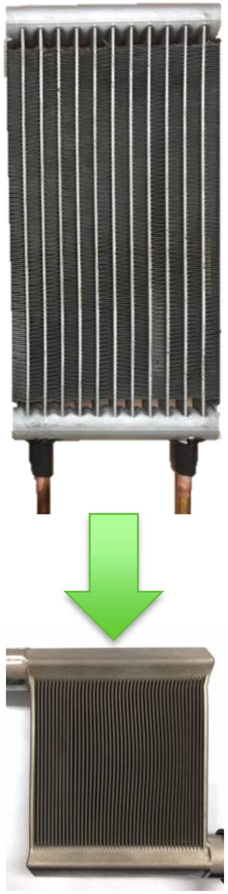
- **Heat eXchangers (HX) are key components in HVAC&R systems**
  - Hold refrigerant charge; impact system efficiency
- **Improved HXs can lead to:**
  - less refrigerant charge
  - less material use, size/weight reduction
  - lower energy consumption, emissions, and costs
- **Challenges in bringing new HX technology to market**
  - Novel designs must be at least 20% better
  - Novel tools that leverage developments in computing, fluid, and structura analyses, e.g., CFD, FEA, optimization algorithms
  - Lack of basic heat transfer and flow fundamentals, correlations
  - Component availability
  - Joining/manufacturing techniques
  - Flow maldistribution
  - Fouling and wetting
  - Noise and vibration

Approach

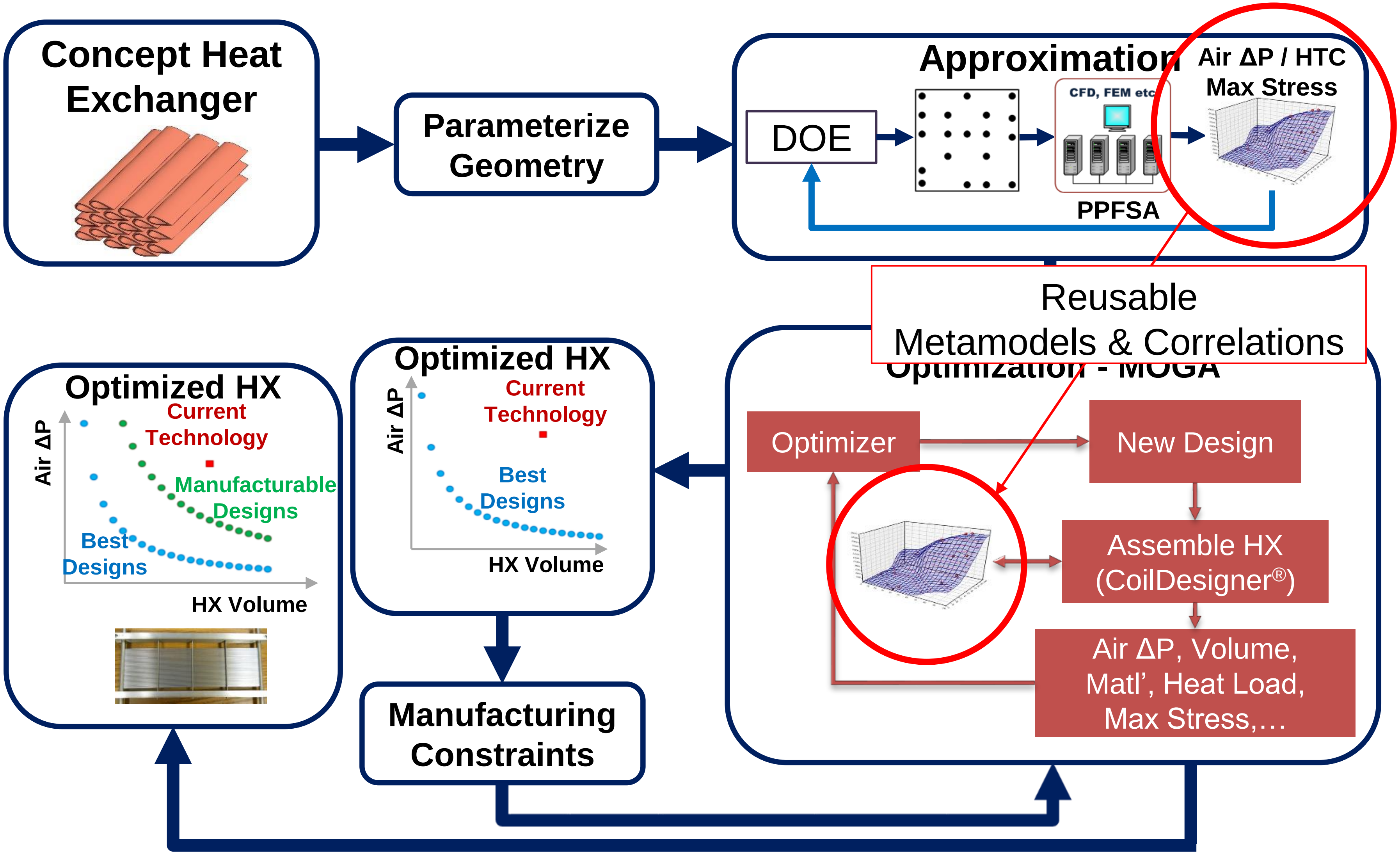
- **Design, fabricate and test high performance air-to-refrigerant HXs with reduced charge and lower weight and size**
  - 30% charge reduction
  - 25% less weight; 25% more compact
- **Develop/establish supporting manufacturing techniques**
  - Small-diameter, non-round tube extrusion
  - Tube/header integration; reduced charge headers
- **Conduct validation tests and address dry/wet operation issues**
  - Mitigate performance degradation during dehumidifying conditions
- **Deliver 3 heat exchanger prototypes to US manufacturers for independent testing and validation**

Impact

- **Impact**
  - New HX designs expected to have 30% reduced charge and at least 25% reduced weight for the same thermal-hydraulic performance
    - 30% refrigerant charge reduction has potential to reduce emissions* by 35 MT CO_2
  - Reduced charge designs will facilitate use of A2L/A3 refrigerants
  - HX design framework applicable to other HXs
    - HX design independent of refrigerant choice
    - Optimized HXs for new refrigerants/blends
  - Size/weight reduction can lead to material, logistics cost savings
  - Non-round tube manufacturing methods will help reduce barrier to entry for potential OEMs and accelerate commercial use
  - Industry involvement in developing and testing new designs with immediate and iterative feedback on commercial viability and T2M
- **Target Market**
  - Residential and commercial air conditioners and heat pumps
  - New construction and retrofit applications



Progress: PPFSA Framework



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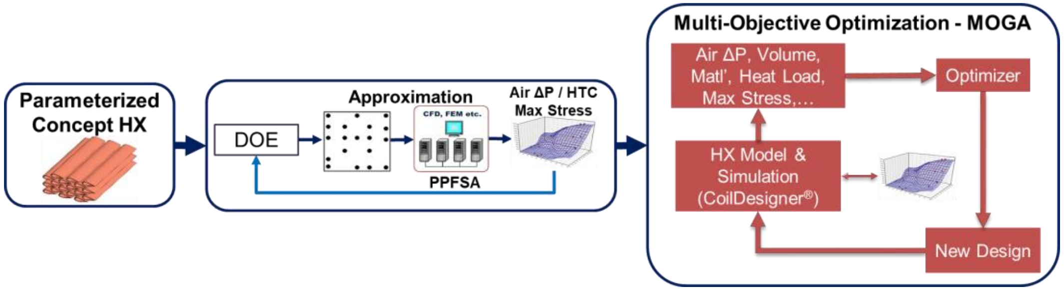
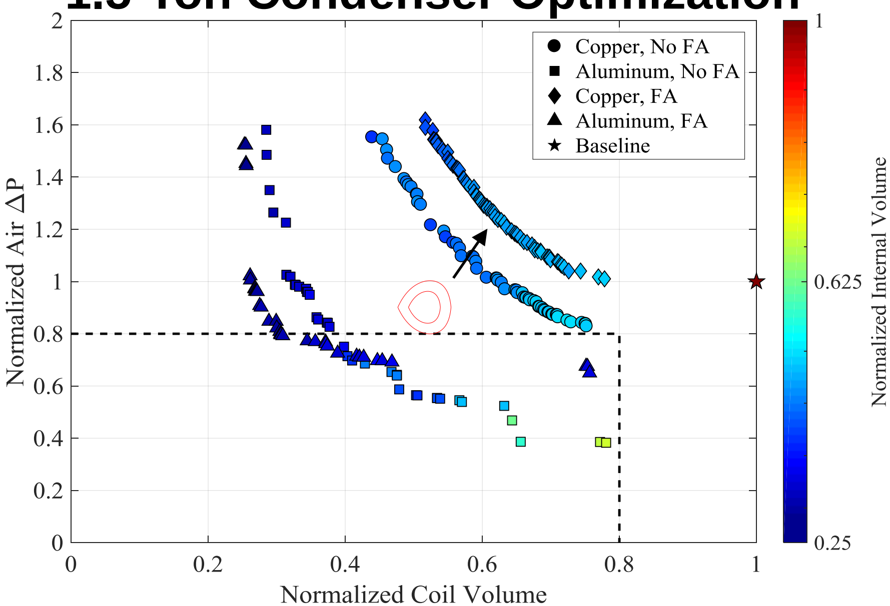
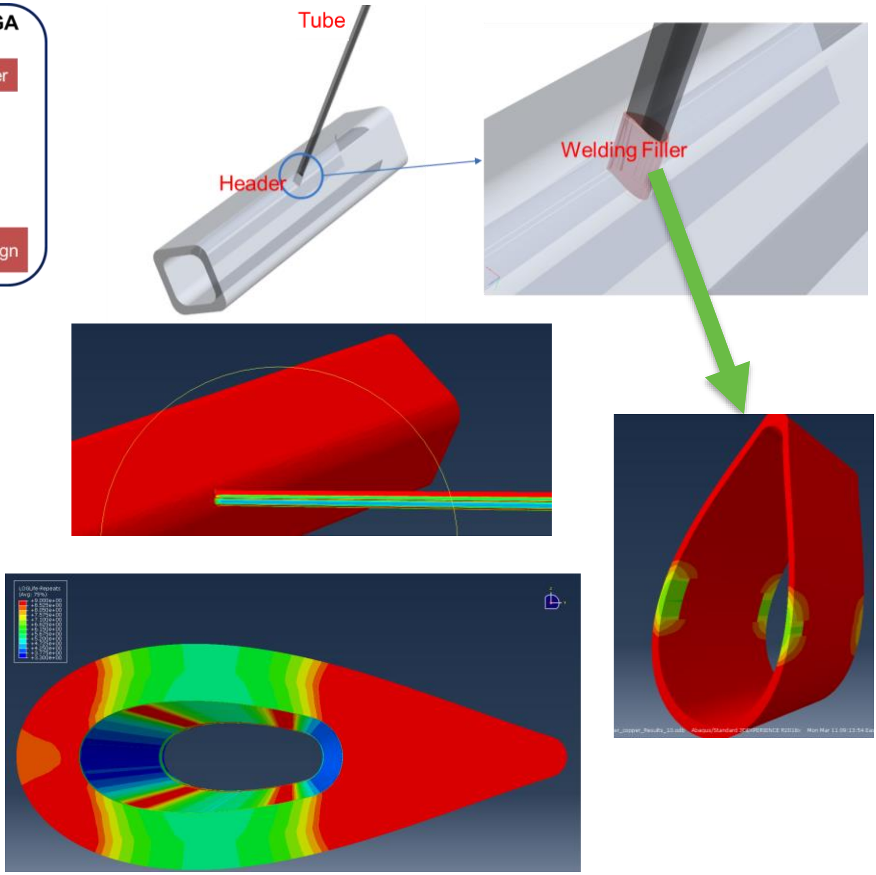
Progress: Analysis & Optimization

- New PPFSA framework developed and exercised to design optimal heat exchangers (radiators and 1.5-Ton condensers)
- Stress analysis for tubes & header assembly



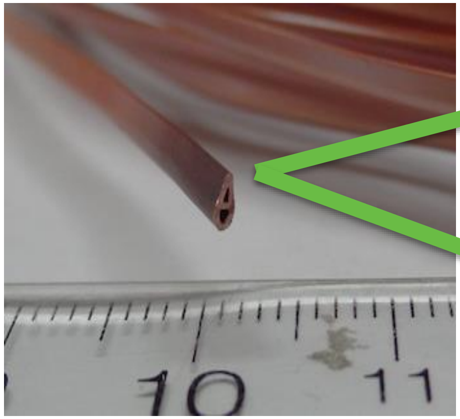
1.5-Ton Condenser Optimization



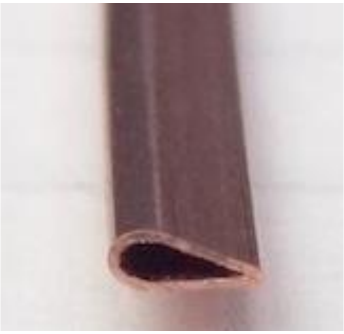


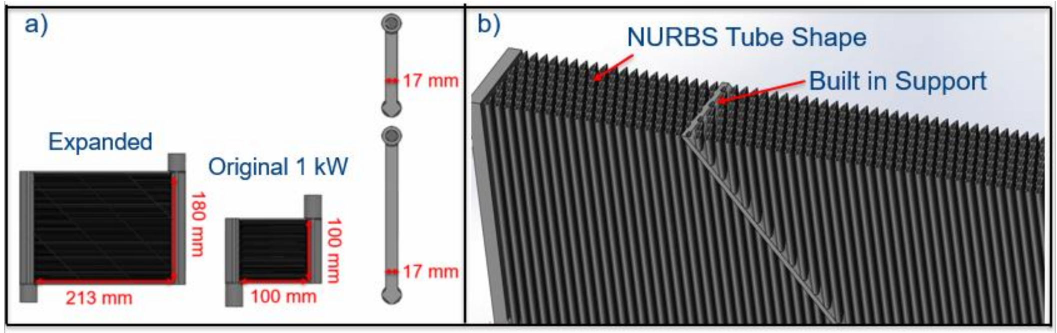
Progress: Fabrication

- **4 tube designs chosen for fabrication**
  - Successful production in copper & brass; pressure tests also successful (2 designs)
- **Investigating 3 different tube-header joining options**
- **Additive Manufacturing for larger build volume (Capacity range 2-5 kW)**



Bar	PSI	I (base) [mm]	II (mid) [mm]	III (tip) [mm]
0	0	1.09 x 2.55	1.09 x 2.55	1.09 x 2.55
50	725	1.09 x 2.55	1.09 x 2.55	1.09 x 2.55
100	1450	1.09 x 2.55	1.09 x 2.55	1.09 x 2.55
150	2175	1.09 x 2.55	1.09 x 2.55	1.09 x 2.55
200	2900	1.09 x 2.55	1.09 x 2.55	1.09 x 2.55





Stakeholder Engagement

Project Integration

- **Collaboration with key project partners to identify and solve manufacturing, testing, and deployment challenges**
  - Al-tube die/tooling is on order
- **First-hand feedback from industry partners of UMD Consortium**

Partners, Subcontractors, and Collaborators

- **Heat Transfer Technologies: Project performer (HX Mfg. process development)**
  - Yoram Shabtay (Co-PI, President); John Black (VP, Market Development)
- **ORNL: Project performer (Advanced manufacturing and testing)**
  - Patrick Geoghegan (Co-PI, R&D Staff); Mingkan Zhang (R&D Staff)
- **Brazeway: Industry partner (Tube manufacturing)**
  - Scot Reagan
- **Ohio University: Subcontractor (Tube manufacturing)**
  - Prof. Frank Craft (Director, Center for Adv. Materials Processing)

Project Communications

- **In-person review meetings**
- **Publications**
  - Klein, E., Hwang, Y., Aute, V., Radermacher, R. A Review of Recent Advances in Additively Manufactured Heat Exchangers, *17th International Refrigeration & Air Conditioning Conference*, West Lafayette, Indiana, USA, July 9-12, 2018. ***In print.***

  - Tancabel, J., Aute, V., Radermacher, R. Review of Shape and Topology Optimization for Design of Air-to-Refrigerant Heat Exchangers, *17th International Refrigeration & Air Conditioning Conference*, West Lafayette, Indiana, USA, July 9-12, 2018. ***In print.***

  - Tancabel, J., Aute, V., Ling, J., Radermacher, R. Design Optimization of High Performance, Reduced Charge Condensers with Novel Tube Shapes, *25th IIR International Congress of Refrigeration*, Montréal, Québec, Canada, August 24-30, 2019. ***Manuscript submitted for review.***

  - Tancabel, J., Aute, V., Ling, J., Radermacher, R. Multi-scale and multi-physics analysis of novel high performance, reduced charge evaporators with novel tube shapes, *9th International Conference on Compressor and Refrigeration*, Xi’an, China, July 10-12, 2019. ***Manuscript submitted for review.***

Remaining Project Work

- **Analysis & Optimization**
  - Finalize 3-5 kW HX designs (In progress)
    - Radiator, Condenser, Evaporator
  - Create models for thermal fatigue, pressure cycling (In progress)
  - Finalize 3-Ton HX designs (Feb. 2020)
- **Fabrication**
  - Investigate novel tube/header joining techniques (In progress)
  - Fabricate 3-5 kW HX designs with new tubes (Aug. 2019)
  - Conduct qualification tests (Feb. 2021)
- **Testing**
  - Two-phase testing of existing prototypes (In progress)
  - Test fabricated 3-5 kW HX designs (Feb. 2020)
    - In-house and independent testing by US manufacturers
  - System-level performance & charge reduction evaluation (Nov. 2020)

Thank You

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Project Budget

Budget History					
01/01/2018– FY 2018 (past)		FY 2019 (current)		FY 2020 – 12/31/2020(planned)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$164,283	$111,391	$67,040	$10,913	$482,101	$30,112

Project Plan and Schedule

Project Schedule												
Project Start: February, 2018		Completed Work										
Projected End: February, 2021		Active Task (in progress work)										
	FY2018				FY2019				FY2020			
Task	Q1 (Feb-Apr)	Q2 (May-Jul)	Q3 (Aug-Oct)	Q4 (Nov-Jan)	Q1 (Feb-Apr)	Q2 (May-Jul)	Q3 (Aug-Oct)	Q4 (Nov-Jan)	Q1 (Feb-Apr)	Q2 (May-Jul)	Q3 (Aug-Oct)	Q4 (Nov-Jan)
Past Work												
Intellectual Property Management Plan												
Current/Future Work												
Develop HX Opt. Framework												
Obtain non-round, small dia. tube designs												
Investigate manufacturing techniques												
Go/No-Go Point 1: Obtain tube Opt. design and manufacturing report												
Design, prototype and test 3 to 5 kW HXs												
Go/No-Go Point 2: Delivery set of in-house validated HXs to US manufacturers for independent validation												
Design, fabricate and test HXs for 3 ton systems												