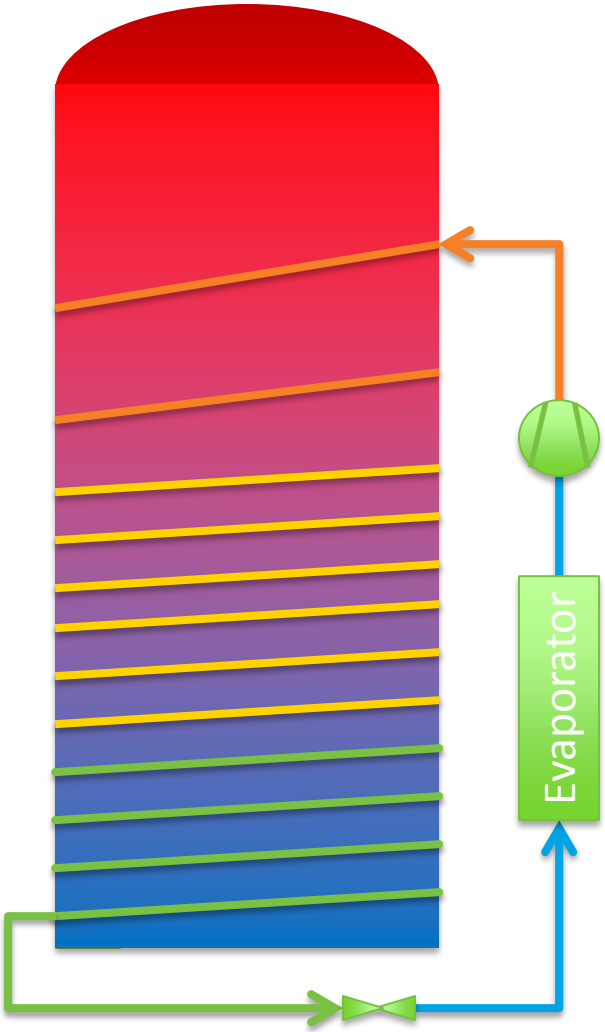
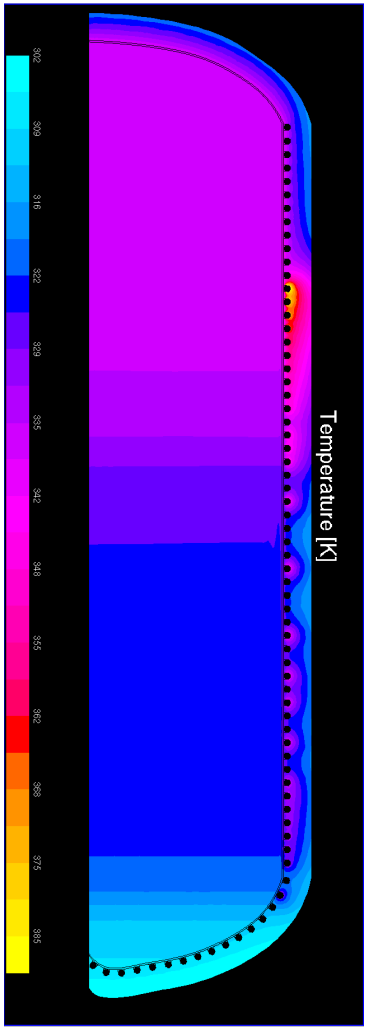
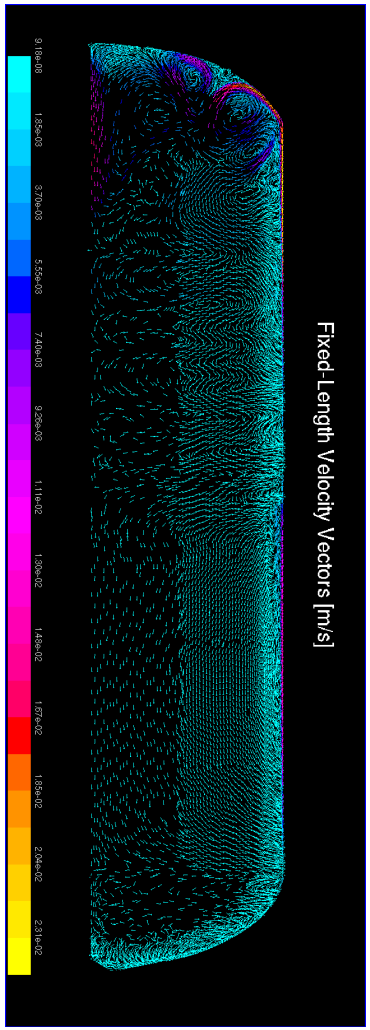
CO_2 Heat Pump Water Heater

2016 Building Technologies Office Peer Review







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

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Project Summary

Timeline:

Start date: Oct 1, 2009

Planned end date: Sep 30, 2016

Key Milestones

1. Go/No-Go: Price premium <$750 compared to baseline HFC HPWH; FY15Q2 (**MET**)
2. Go/No-Go: EF>2.0 and FHR>50 gallon to meet ENERGY STAR qualification criteria; FY14Q4 (**MET**)

Budget:

Total DOE to Date: $2,367k

Total Project: $2,435k

Key Partners:

GE Appliances	CRADA partner

GE Appliances

Project Outcome:

Demonstrate a more affordable path to an ENERGY STAR-qualified residential CO_2 HPWH with low GWP, configured for price point appropriate to US market.

Purpose and Objectives

Problem Statement:

- Heat pump water heaters can save significant energy, however they currently use refrigerants with high GWP.
- Low-GWP CO_2 heat pump water heaters exist, but existing product first cost is too high for widespread adoption in the US residential market.

Target Market and Audience

Electric water heaters currently use 1.4 Quads/yr.

Impact of Project

- CO_2 heat pump water heater at price point viable for the US residential market
- Technical potential of increasing EF from 0.92 to 2.0 is savings of 0.8 Quads/yr
- Using CO_2 as a refrigerant, this can be done with near-zero GWP and zero ODP

Approach

Approach: Utilize low-cost components; maintain ENERGY STAR rating

- Single-speed compressor, single expansion device
- Optimized *wrap-around* gas cooler replaces double-wall *external* gas cooler

Key Issues: Cost of CO_2 components, thermodynamic characteristics of CO_2, need for careful gas cooler wrap-around coil design

Distinctive Characteristics: Heat pump water heater with natural refrigerant (inexpensive with GWP=1)

Characteristic	External heat exchanger	Wrap-around heat exchanger
Cost	✗ High	✓ Low
Water fouling	✗ Significant challenge	✓ None
Water pump	✗ Required	✓ Not required
Additional tank water inlet/outlet ports	✗ Required	✓ Not required
Performance	✓ Good	? Needs research

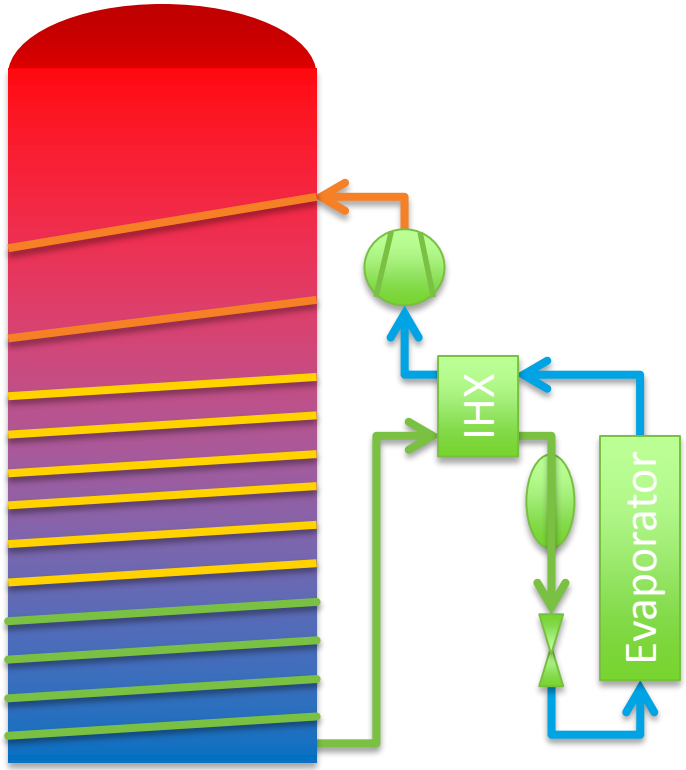
Approach

Context:

- EcoCute CO_2 water heaters (a few million units in Japan, Europe and Australia)
  - First cost: ~6,000 $US, plus installation (4-5 kW heat pump heating capacity)
  - Variable speed compressor
  - External heat exchanger and circulation pump; stratified tank
  - Electronically controlled expansion valves and sophisticated controls
- HFC-based HPWHs
  - Available in US from various manufacturers, ~$1,000 (2-3 kW heat pump heating capacity)
  - Wrap-around condenser coil; non-stratified tank
  - Max water temperature limited

Approach

This project:



EcoCute:

Additional elements:

- Split system (high installation cost)
- Inverter-driven compressor
- Electronic expansion valves
- Variable speed pump
- External gas cooler

Approach

Wrap-around vs. external (e.g. plate or tube-in-tube)

Characteristic	External heat exchanger	Wrap-around heat exchanger
Cost	✗ High	✓ Low
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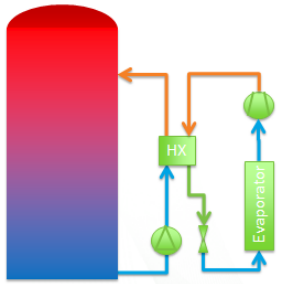

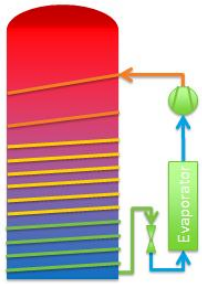

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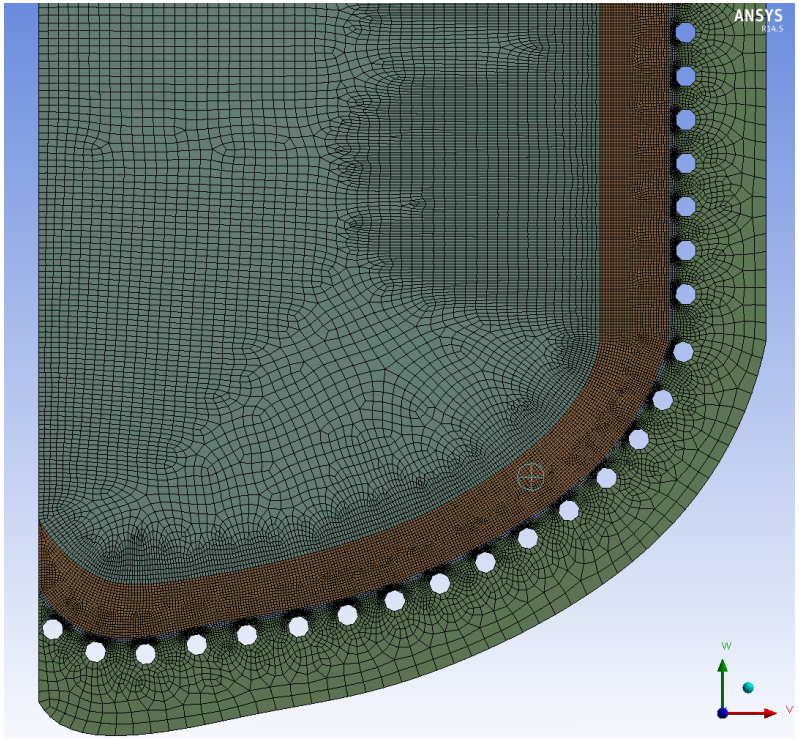
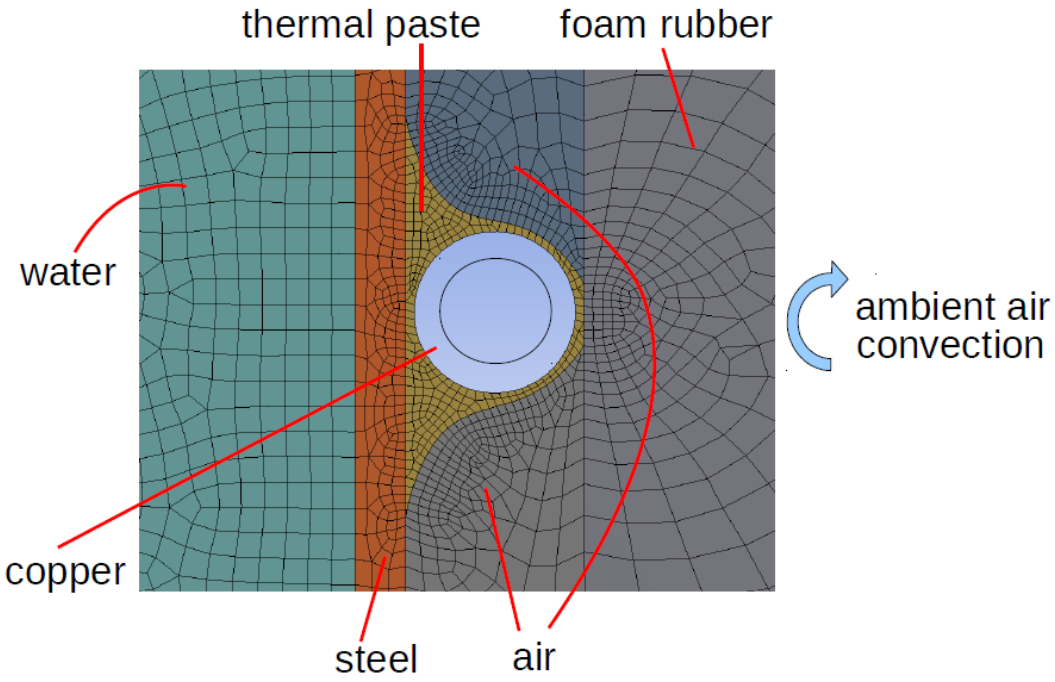
Progress and Accomplishments

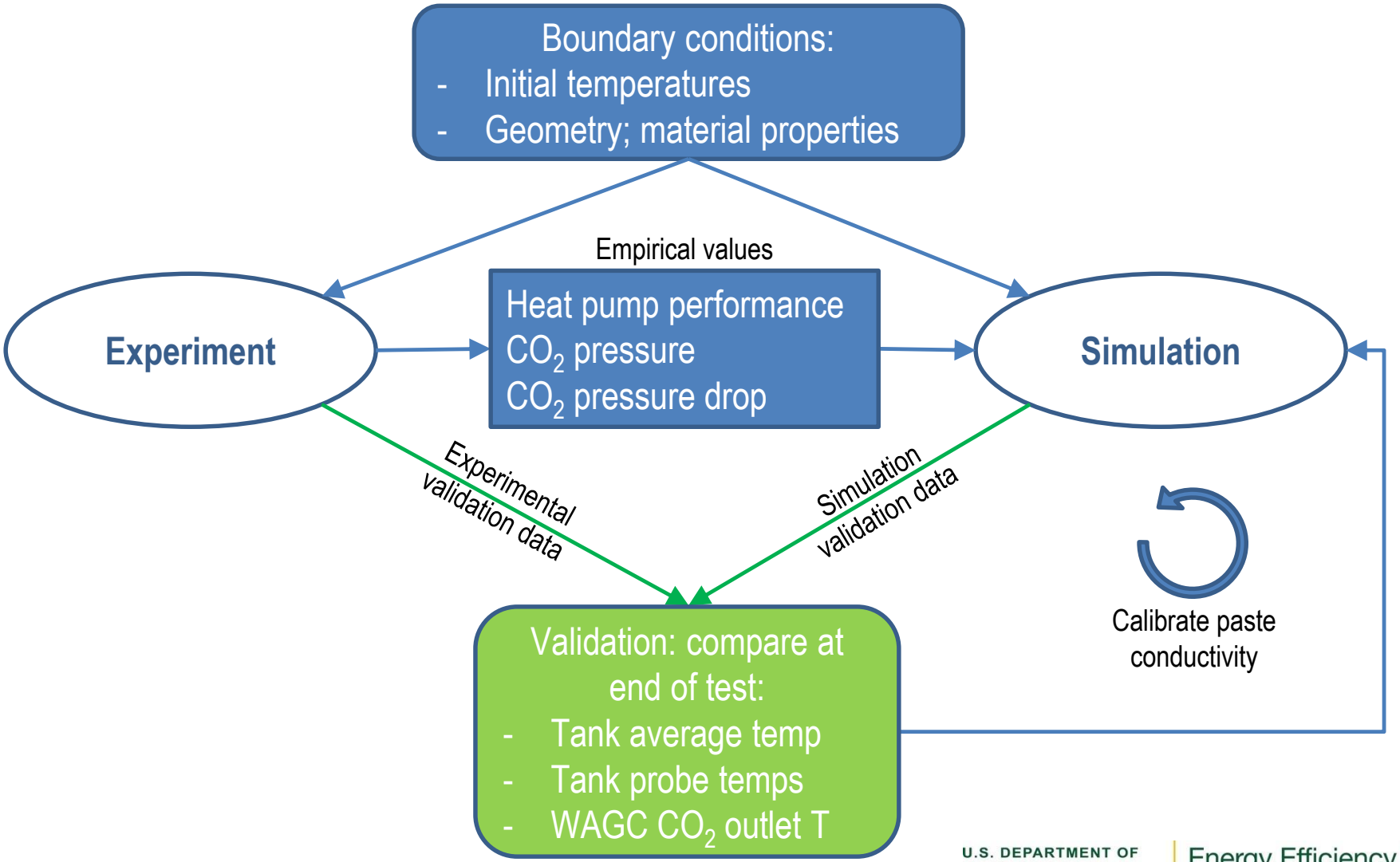
Accomplishments: Constructed coupled tank-heat pump design tool in ANSYS to evaluate wrap-around coil designs





Progress and Accomplishments

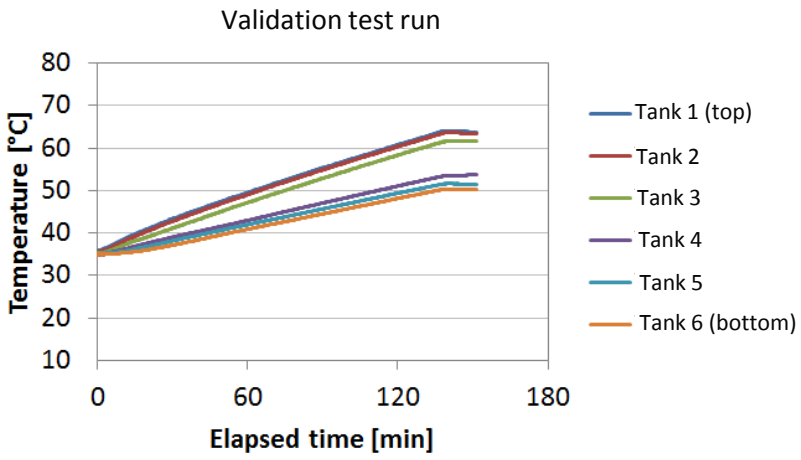
Accomplishments: Validation of design tool

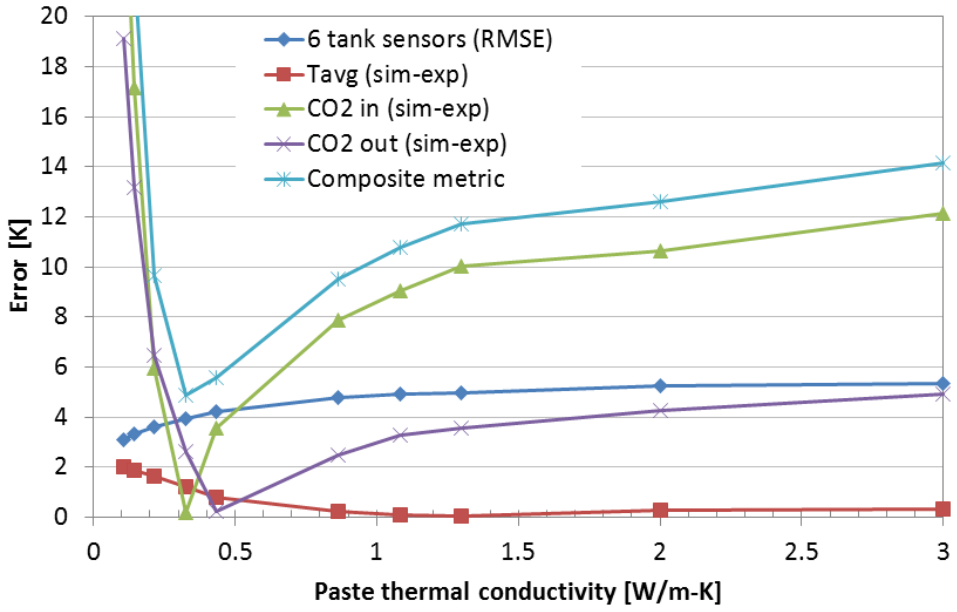


Progress and Accomplishments

Accomplishments: Validation of design tool

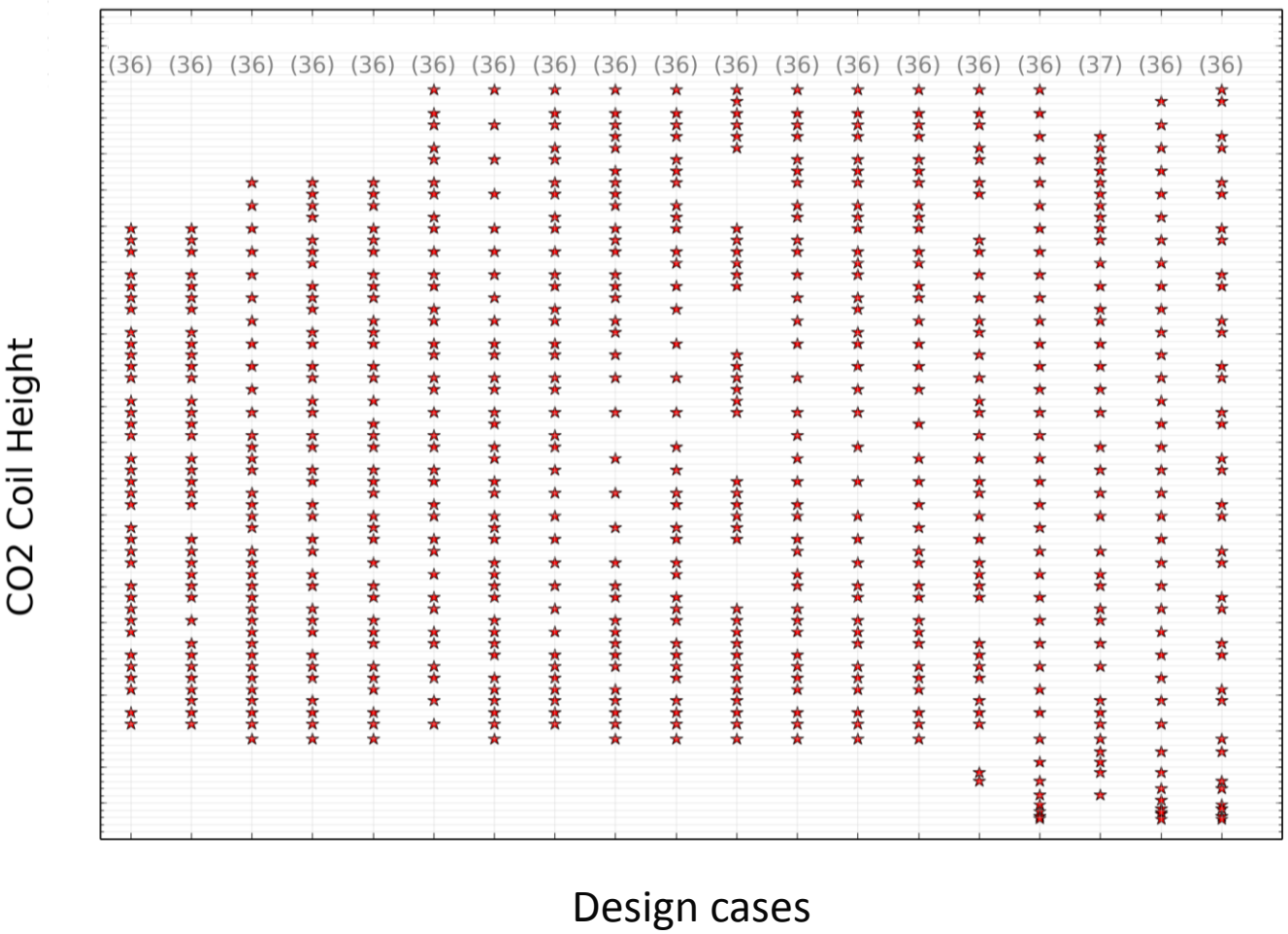
- Thermal conductivity of CFD mesh's thermal paste treated as free variable (representing contact resistance)
- Experimental data from second WAGC (improved construction)
- Good agreement found at 0.4 W/m-K

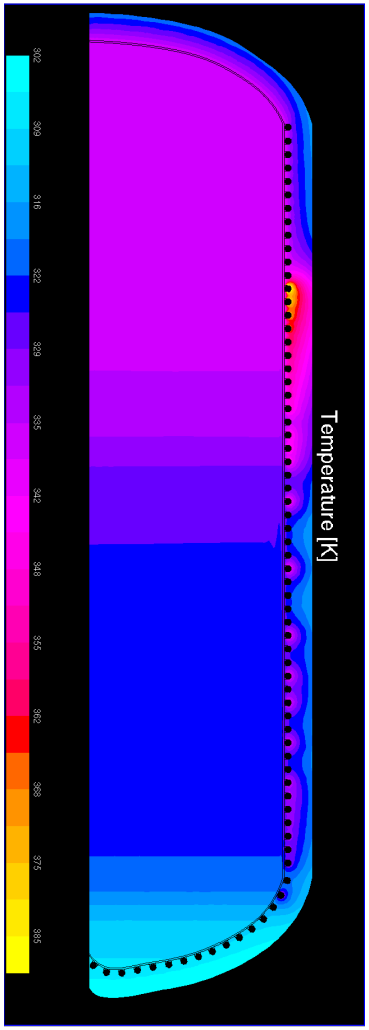




Progress and Accomplishments

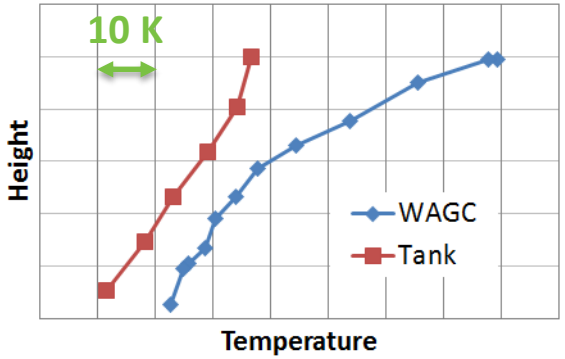
Accomplishments: Evaluation of designs with CFD





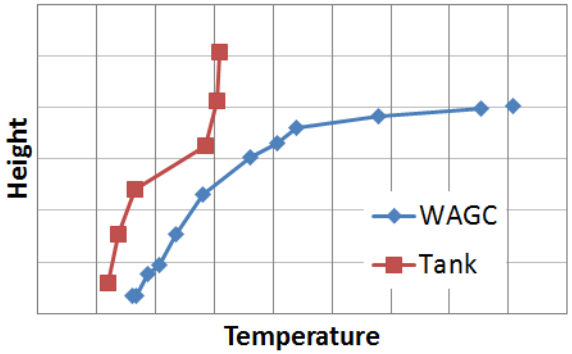
Progress and Accomplishments

Accomplishments: Progressive improvements in wrap-around gas cooler (WAGC)



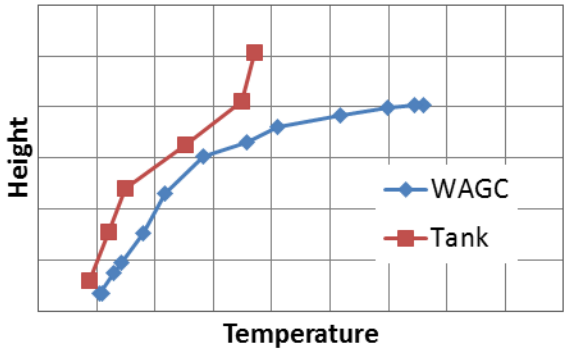
Temperature approach at the pinch: ~10 K

Improved coil construction with insights from CFD



Temperature approach at the pinch: ~5 K

CFD-aided design



Temperature approach at the pinch: ~2.5 K

Progress and Accomplishments

Lessons Learned:

- CFD validation is not a straightforward problem; especially with a dynamic system coupled with nonlinear boundary condition
- CO_2 system components are not readily available, e.g. low cost compressors at desired capacity

Accomplishments:

- Development of validated CFD model
- Fabrication and validation of optimized wrap-around gas cooler design
- Achieving EF of 2.1 with prototype CO_2 HPWH based on low cost components (single speed compressor, single XV, wrap-around gas cooler)
- Achieved projected installed price premium <$750

Market Impact:

- We have demonstrated a more affordable path to ENERGY STAR-rated CO_2 HPWH (low GWP – no direct environmental impact)
- Sentech/SRA market assessment showed an estimated 72,000 – 180,000 total unit shipments five years following commercial viability to account for 0.037 Quads in annual national primary energy savings

Awards/Recognition:

- None yet

Project Integration and Collaboration

Project Integration:

- Participate in 2013 and 2016 ACEEE Hot Water Forums
- Discuss with industry partners
- Participate in different venues and activities including DOE water heating roadmap workshop

Partners, Subcontractors, and Collaborators:

- General Electric Appliances
  - Natarajan Venkatakrishnan, Director Advanced Technologies
  - Craig Tsai, PI

Communications:

Publication in progress for wrap-around coil CFD design tool

Next Steps and Future Plans

Next Steps and Future Plans:

- Evaluate UEF (in addition to the EF already evaluated)
- Prepare final report

REFERENCE SLIDES

Project Budget

Project Budget: 2,435k
Variances: None
Cost to Date: 2,367k
Additional Funding: Cost share from CRADA partner

Budget History					
FY2010 – FY 2015 (past)		FY 2016 (current)		FY 2017 (planned)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$2,358k	*	77k	*	0	0

* In-kind contribution from CRADA partner – exact total is confidential information

Project Plan and Schedule

- Go/no-go decision point met with EF>2.0
- Go/no-go decision point met for installed cost premium <$750