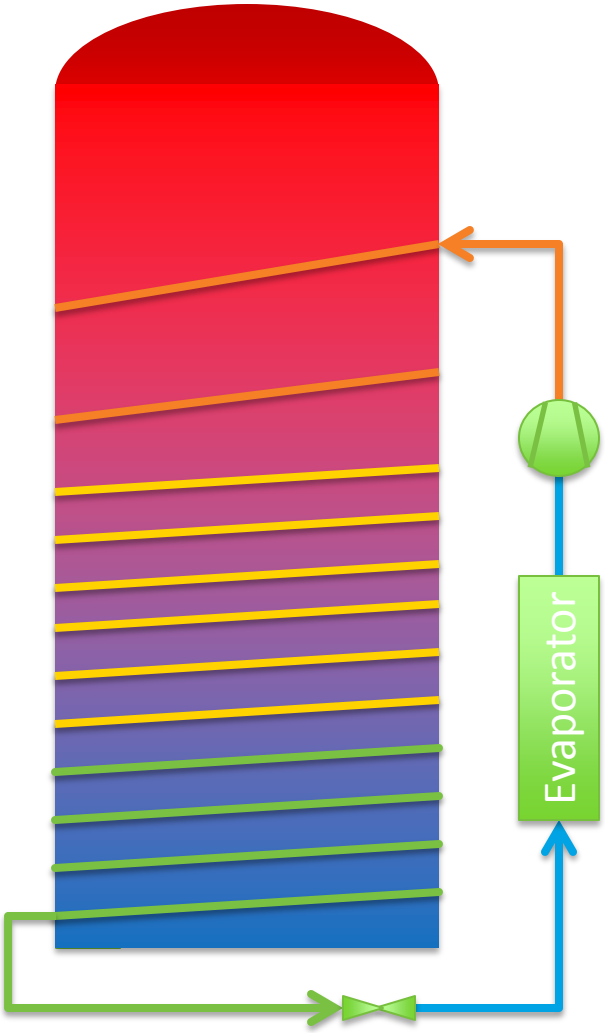
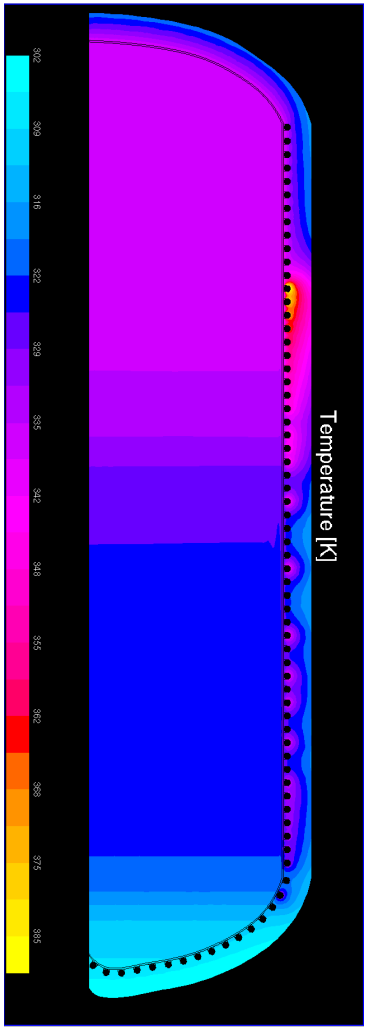
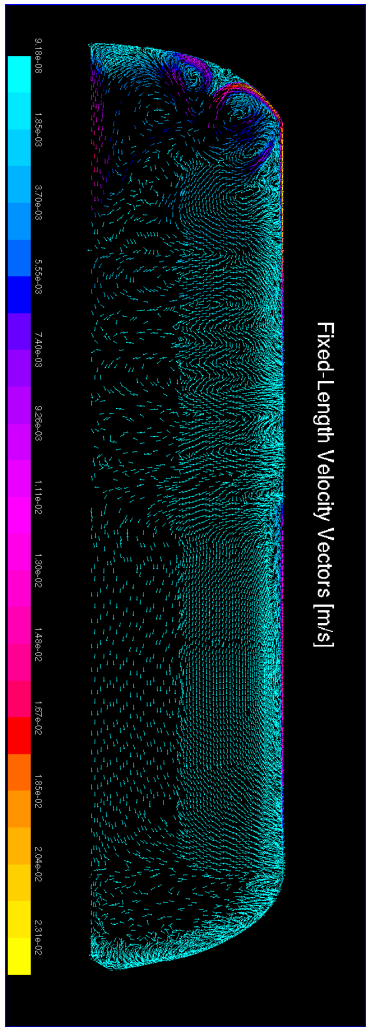
CO_2 Heat Pump Water Heater

2014 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, 2015

Key Milestones

1. Optimize wrap-around coil; Dec 2013
2. Achieve EF>2.0; March 2014

Budget:

Total DOE $ to date: $2,147k

Total future DOE $: $200k

Target Market/Audience:

Residential electric water heating

Key Partners:

GE Appliances	CRADA partner

GE Appliances

Project Goal:

Develop CO_2 heat pump water heater that meets Energy Star standards for HPWHs at an installed cost that will enable widespread adoption in US residential market.

Purpose and Objectives

Problem Statement:

- Heat pump water heaters can save significant energy, however they currently use refrigerants with high GWP.
- Low-GWP heat pump water heaters based on CO_2 exist, but first cost of existing products is too high to enable 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 performance

- Single-speed compressor, single expansion device
- Optimized *wrap-around* gas cooler instead of 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

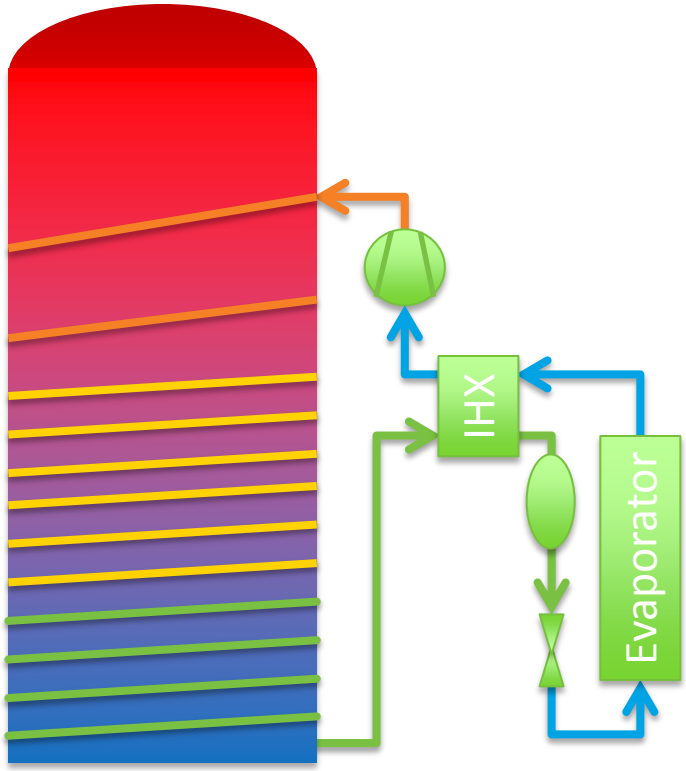
Approach

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:



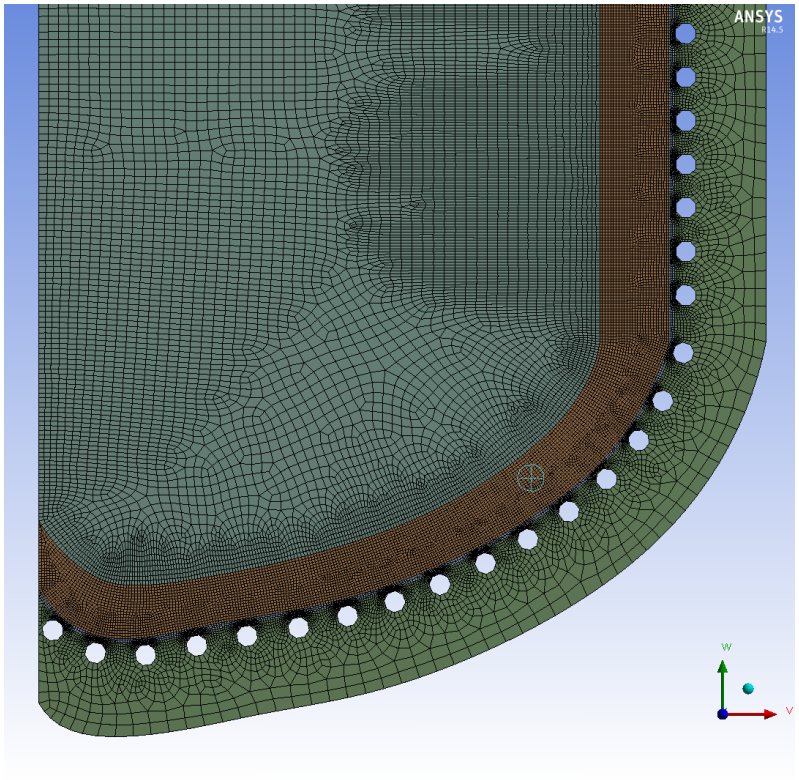
EcoCute:

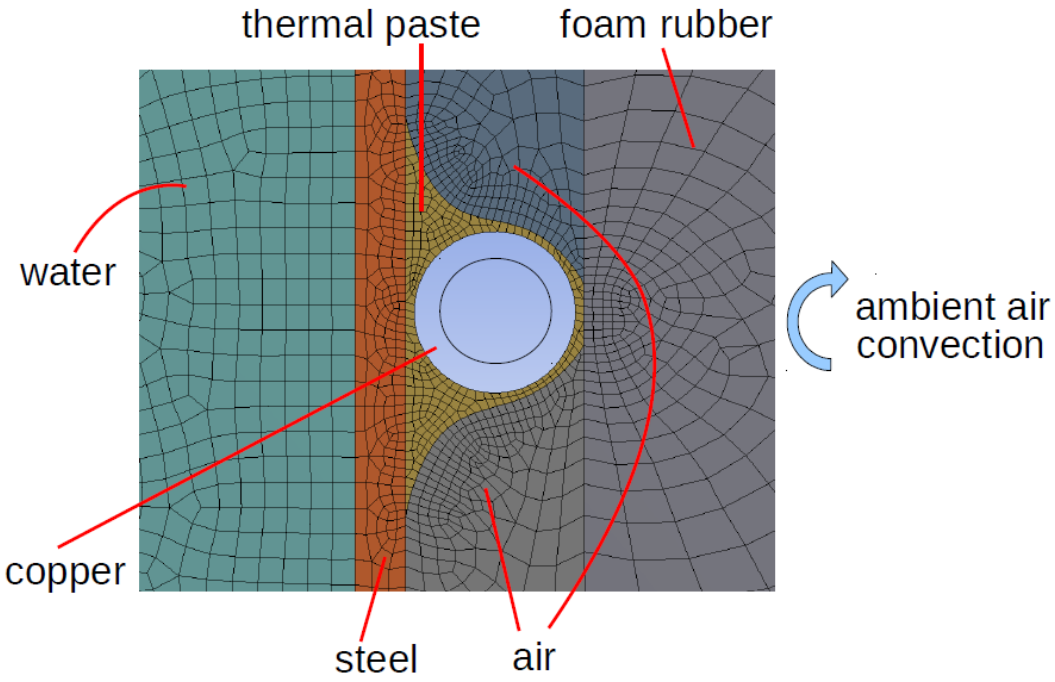
Additional elements:

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

Progress and Accomplishments

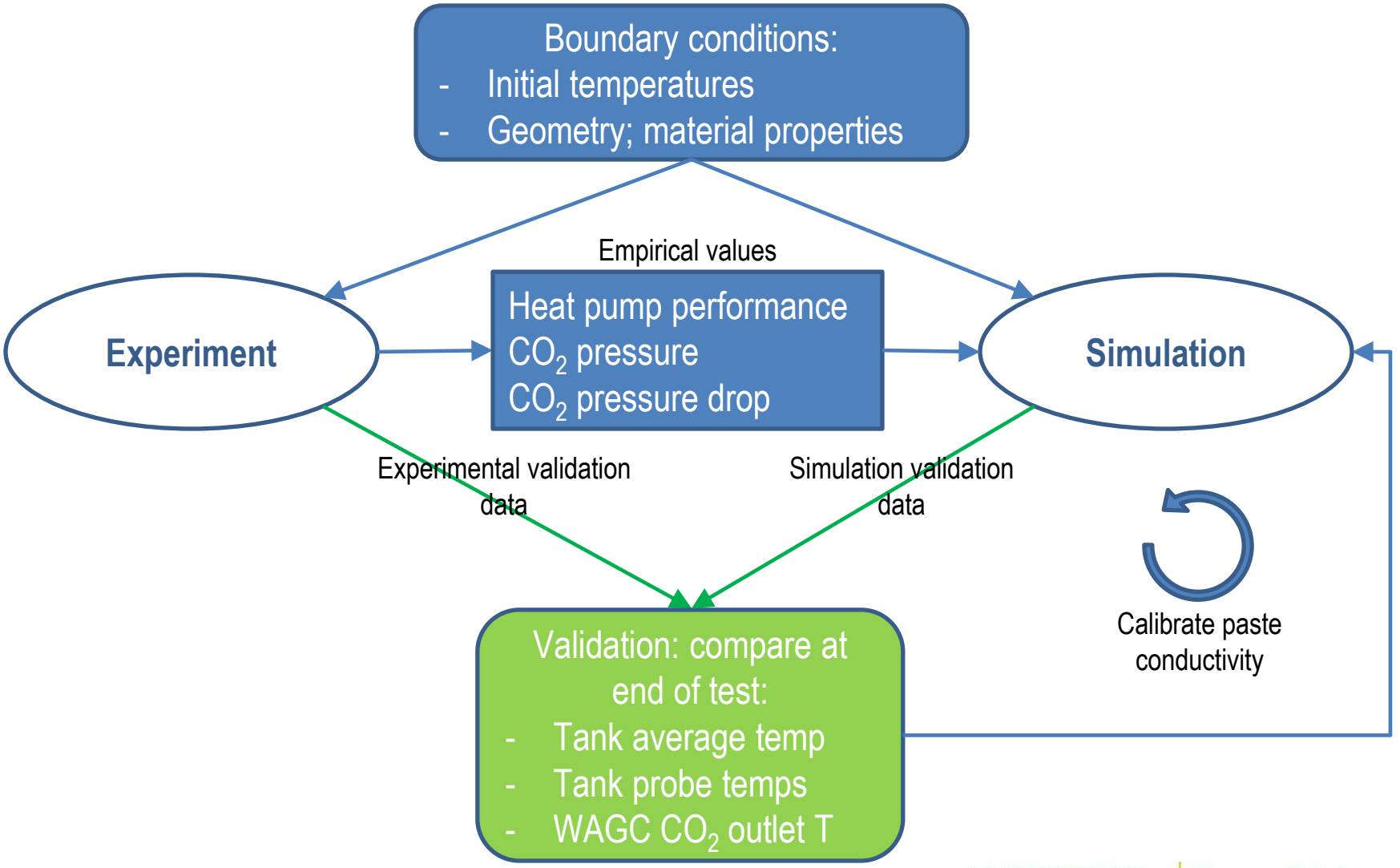
Accomplishments: Constructed coupled tank-heat pump design tool in ANSYS to evaluate wrap-around coil designs





Progress and Accomplishments

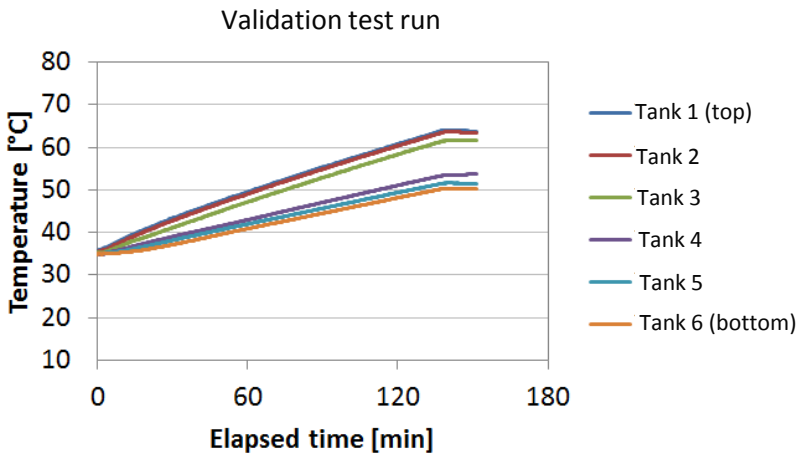
Accomplishments: Validation of design tool

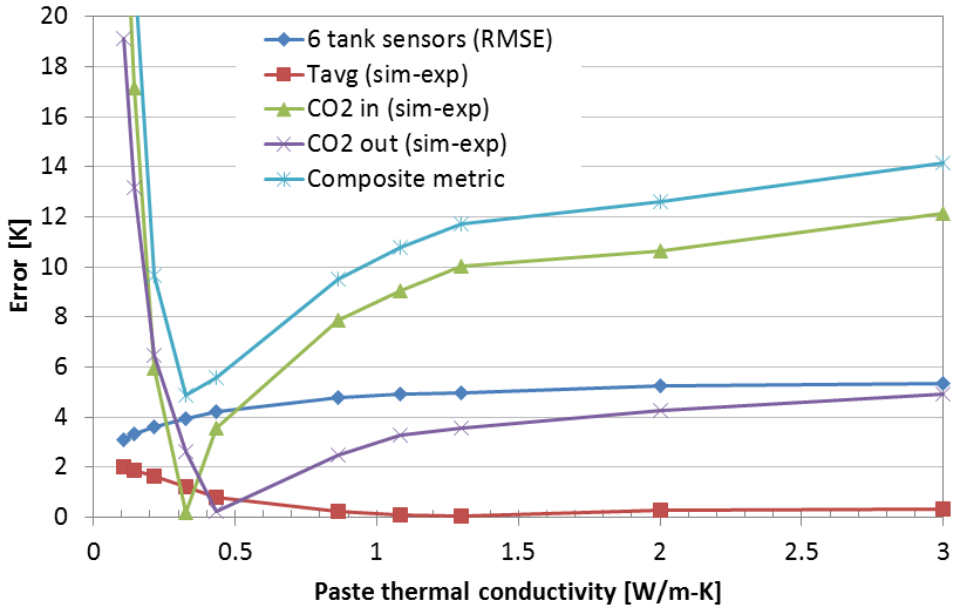


Progress and Accomplishments

Accomplishments: Validation of design tool

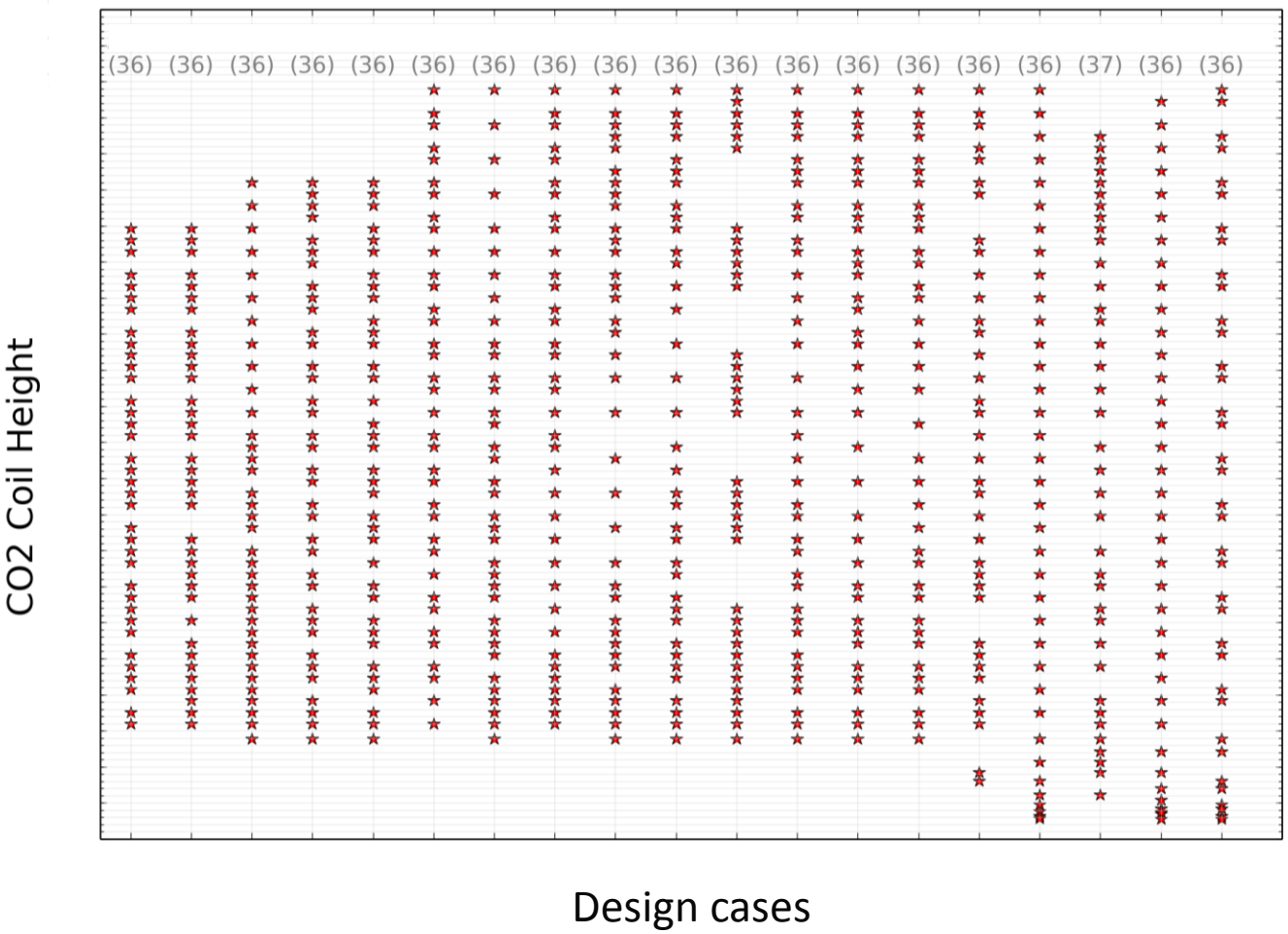
- Thermal conductivity of CFD mesh's thermal paste treated as free variable (representing contact resistance)
- Experimental data from second WAGC (improved construction)
- Good agreement found at 0.4 W/m-K

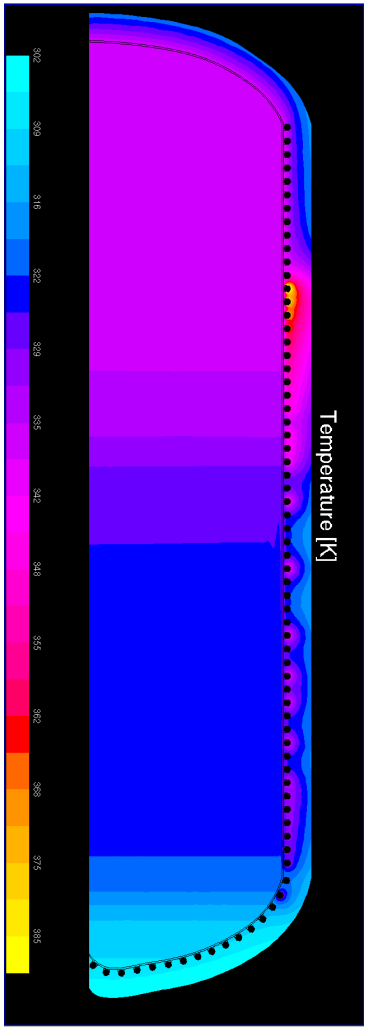




Progress and Accomplishments

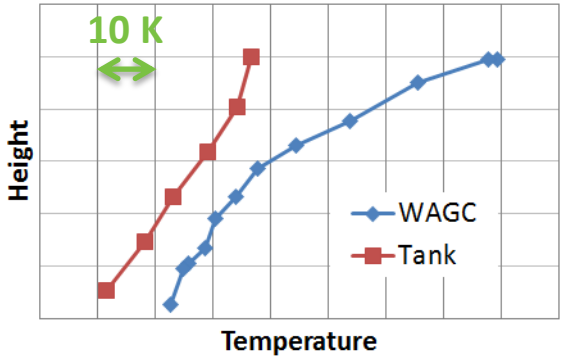
Accomplishments: Evaluation of designs with CFD





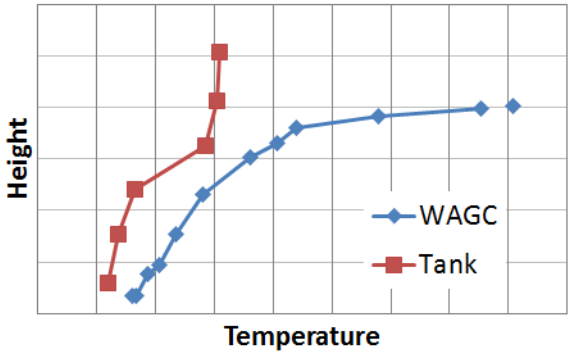
Progress and Accomplishments

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



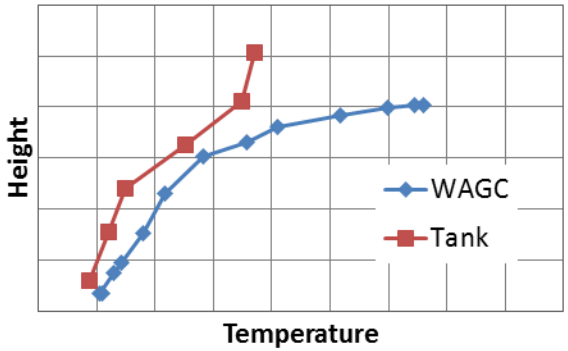
Temperature approach at the pinch: ~10 K

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)

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 37,000 – 112,000 total unit shipments one year following commercial viability, and 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 ACEEE Hot Water Forum”
- Discuss with industry partners
- Participate in different venues and activities like the 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 cold climate performance
- Evaluate performance at different air temperatures without high side pressure management
- Develop next generation prototype
- Optimize design for fixed charge

REFERENCE SLIDES

Project Budget

Project Budget: DOE total $2,347k FY2010 - FY2015
Variances: None
Cost to Date: $2,010k through Feb 2014
Additional Funding: None expected

Budget History					
FY2010 – FY2013 (past)		FY2014 (current)		FY2015 (planned)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$1,797k	*	$350k	*	$200k	*

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

Project Plan and Schedule

- Delays in FY2013 under transition of ORNL PI and CFD validation issues
- Go/no-go decision point met with EF>2.0