Thermoelectric HVAC and Thermal Comfort Enablers for Light-Duty Vehicle Applications

Clay W. Maranville
Ford Motor Company

May 17, 2013

Project ID # ACE047

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Overview

Timeline

- Start: Oct. 2009
- End: Aug. 2013
- Percent complete - 88%

Budget

- Total project funding: $8.48M
  - DOE share: $4.24M++
    ++ Includes direct funding to NREL
  - Contractor share: $4.24M
- DOE funding received in FY12:
  - $421,832 (Oct-11 to Sep-12)
- DOE funding projection for FY13:
  - $488,482 (Oct-12 to Sep-13)
- DOE funding to-date: $2.89M**

** Does not include direct funding to NREL

Barriers#

- **Barriers**
  - Cost
  - Scale-up to a practical thermoelectric device
  - Thermoelectric device / system packaging
  - Component / system durability
- **Targets**
  - By 2015, reduce by > 30% the fuel use to maintain occupant comfort with TE HVAC systems.
  - Develop TE HVAC modules to augment MAC system
  - Integrate TE HVAC into vehicle. Verify performance and efficiency benefits.
  - Validate efficiency improvements with next-gen TE.

Partners

- **Interactions/ collaborations:**
  - Visteon, Gentherm, NREL, Ohio State University
- **Project lead:** Ford Motor Company

Barriers & targets listed are from the VT multi-year program plan: http://www1.eere.energy.gov/vehiclesandfuels/pdfs/program/vt_mypp_2011-2015.pdf

Relevance / Objectives

Project Goal:

Identify and demonstrate technical and commercial approaches necessary to accelerate deployment of zonal TE HVAC systems in light-duty vehicles

Program Objectives:

- Develop a TE HVAC system to optimize occupant comfort and reduce fuel consumption
- Reduce energy required from AC compressor by 1/3
- TE devices achieve $COP_{cooling} > 1.3$ and $COP_{heating} > 2.3$
- Demonstrate the technical feasibility of a TE HVAC system for light-duty vehicles
- Develop a commercialization pathway for a TE HVAC system
- Integrate, test, and deliver a 5-passenger TE HVAC demonstration vehicle

Technical Approach: Overall Program

- Develop test protocols and metrics that reflect real-world HVAC system usage
- Use a combination of CAE, thermal comfort models, and subject testing to determine optimal heating and cooling node locations
- Develop advanced thermoelectric materials and device designs that enable high-efficiency systems
- Design, integrate, and validate performance of the concept architecture and device hardware in a demonstration vehicle

Relevance / Accomplishments

FY2012 (Oct ‘11 to Sep ‘12) Objectives / Accomplishments:

- Initiated TE component fabrication and bench testing
- Completed evaluation of advanced TE heating/cooling materials
- Completed advanced TE materials feasibility assessment
- Fabrication of all major prototype components underway
- Initiated system and component cost analysis
- Initiated ancillary loads trade-study
- Continued thermal comfort modeling toolset development
- Finalized Bill-of-Material components for prototype vehicle integration

FY2013 (Oct’12 to Sep ‘13) Objectives:

- Completed TE component fabrication and bench testing
- Fabrication of all major prototype components completed
- Completed system and component cost analysis
- Installed TE HVAC system components, DAQ, and system controls into demonstration vehicle
- Complete ancillary loads study (March) and comfort model development (Aug)
- Develop system operation calibration strategy for vehicle tests (May)
- Complete TE HVAC commercialization assessment (May)
- Develop advanced TE HVAC commercial & technical roadmap (May)
- Conduct objective and subjective vehicle-level tests of TE HVAC system (June - Aug)
- Conduct thermal comfort model / zonal system modeling assessment correlation (Aug)
- Demonstrate completed demonstration vehicle to DOE & CEC (Sep - Oct)

Critical-Path Milestones: FY12, FY13

Month/Year	Milestone	Status
Nov- 11	Thermal comfort modeling toolset functionality assessed for spot-comfort	Complete
Sep-11	TE HVAC assembly specification development completed	Complete
Dec-11	Empirical buck-modeling validation studies completed CAE and comfort models completed on final system architecture	Complete
Mar-12	Proof-of-principle TE unit, bench study, and model comparisons completed	Complete
Jun-12	Detailed CAD and packaging studies completed on TE HVAC	Complete
Sep-12	Updated results from advanced TE materials research	Complete
Sep-12	Design complete for vehicle-intent Electrical Power/Control, Air Handling, Liquid, and Central HVAC	Complete
Dec-12	Bench testing completed on vehicle-intent TE device hardware	Complete
Nov-12	System cost analysis completed	Complete
Jan-13	Integrated TE device system bench validation testing completed All component fabrication completed	Complete
Mar-13	Final integration of vehicle with TE HVAC system completed	Delay to Apr-13
Mar-13	Ancillary load analysis study completed	On-track
May-13	Commercialization study completed	On-track
May-13	Advanced TE materials and devices R&D completed	On-track
Aug-13	TE HVAC climate system performance and energy consumption testing completed TE HVAC objective thermal comfort testing completed TE HVAC subjective thermal comfort testing completed	On-track
Aug-13	Final FE model validated against test results	On-track
Aug-13	Comfort model validated against baseline and modified vehicle test results	On-track
Sep-13	Vehicle demonstrated to DOE	On-track

Go / No-Go Decision Points

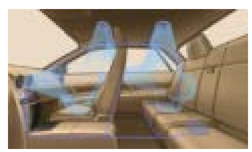
Month/ Year	End of Phase Go / No-Go Decision	Status
	Phase 3	
Nov – 12	Vehicle-intent TE based subsystems meet bench-level performance and durability tests	Met
Nov – 12	Cost analyses shows a potential business case for a TE HVAC system in the specified timeframe	Met
	Phase 4	
Aug – 12	TE HVAC system meets comfort performance criteria specified in program objectives	
Aug – 12	TE HVAC system improves fuel economy compared with baseline vehicle	
Aug – 12	Cost study and commercialization analysis show TE HVAC commercial pathway for 2012-2015	
Aug – 12	Measured COP meets program objectives	

System Level Approach Required to Minimize Energy Use

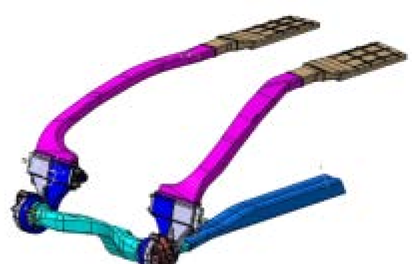
System Level Solution

Reduce Thermal Loads

Efficient Delivery Zonal Concept

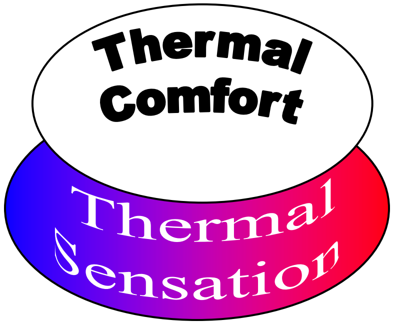


Efficient Equipment TE HVAC



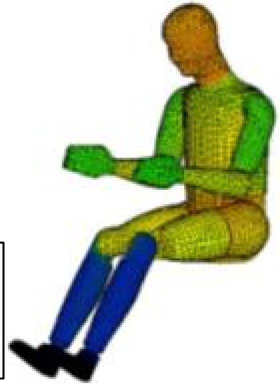
Integrated Modeling Approach Validated by Early Testing

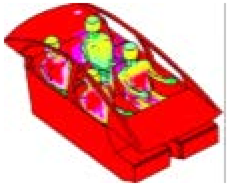
Thermal manikin compared to trained climate control observer
Temperature, sensation, comfort



Design impacts performance
Design for comfort
and
energy efficiency

Thermal manikin helps to validate virtual manikin
Segment temperature,
sensation, comfort





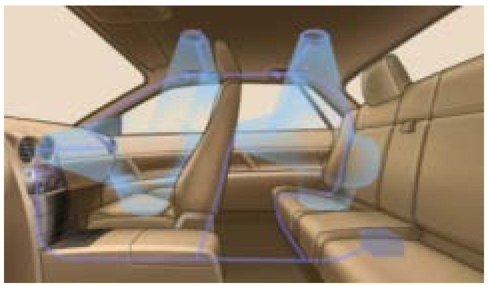
Reduced thermal load

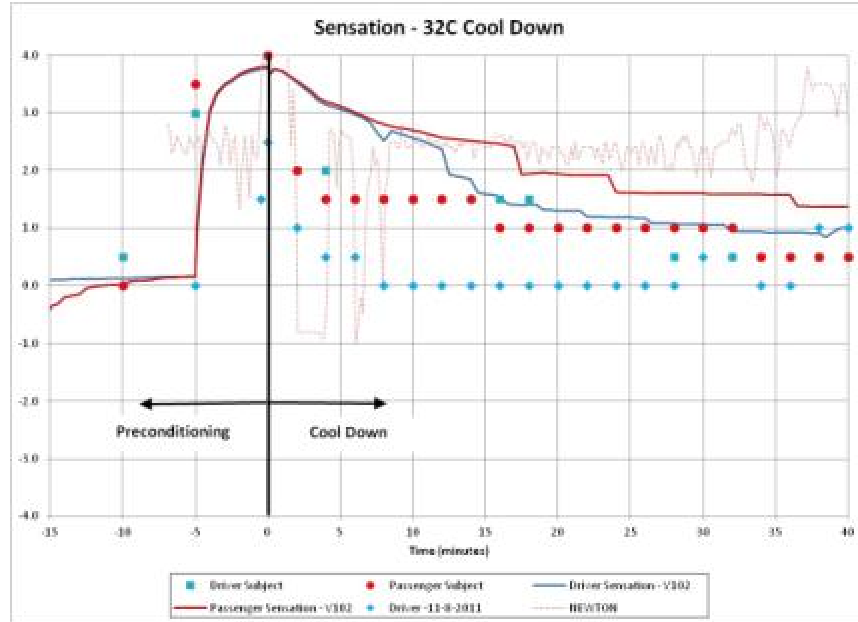
CAE tool guides design
Zonal climate control

Technical Accomplishment:
Vehicle System Trade Studies to Optimize Design

Comfort Model Validation

- Validate zonal system with CAE, manikin and subject data

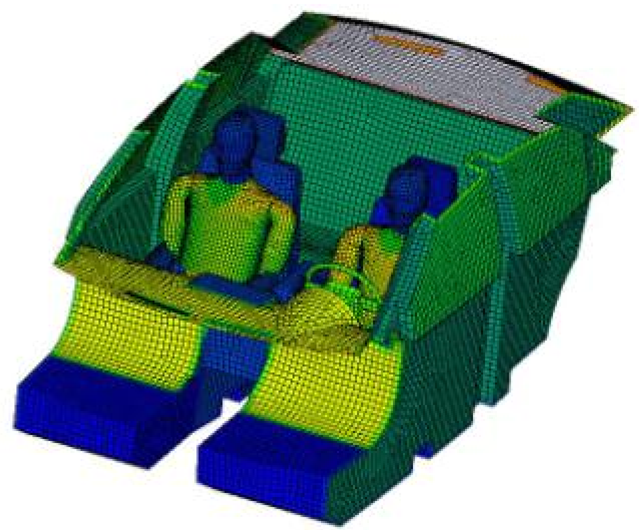




Ancillary Load Reduction Impact

Determining the comfort/energy/cost impacts of:

- Glazing – IR reflective or absorptive
- IP – low mass, IR reflective
- Body insulation
- Parked car ventilation
- Heated seats and other surfaces



Technical Approach

Halla Visteon Climate Control

The approach to develop a zonal climate system has been broken into 4 phases:

Phase 1

- ✓ Developed test conditions, measures of success and test methodology
- ✓ Benchmarked testing of conventional HVAC configurations.
- ✓ Evaluated perceived comfort for multple configurations of a zonal climate system

Phase 2

- ✓ Utilize CAE/CFD tools , including comfort models, for rapid evaluation of potential system architectures and confirmation of selected architecture before building & testing
- ✓ Conduct subjective tesing for perceived comfort in vehicle buck to confirm CAE/CFD
- ✓ Develop design requirements for TED and base system

Phase 3

- ✓ Design components and subsytems to meet requirements from Phase 2 (CAE/CFD)
- ✓ Fabricate components and subsystems
- ✓ Validate component and subsystem performance – bench testing

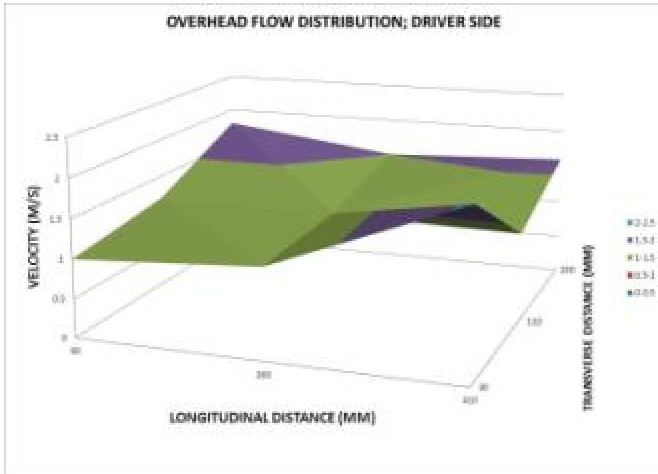
Phase 4

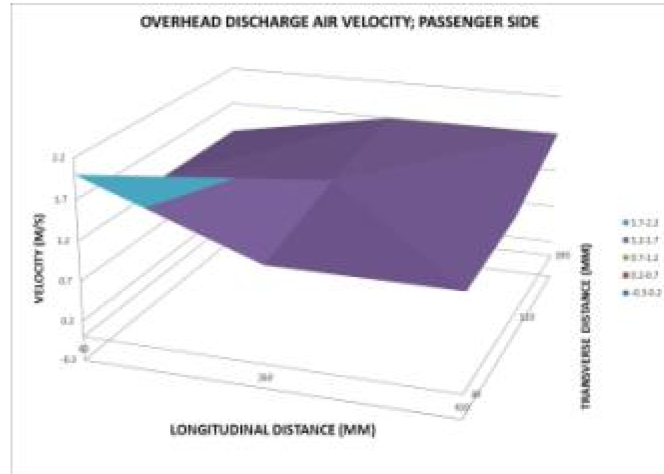
- Integrate zonal climate system components into vehicle & validate system performance

Technical Accomplishments - Results

HCC Visteon
Halla Visteon Climate Control

Airflow System Results



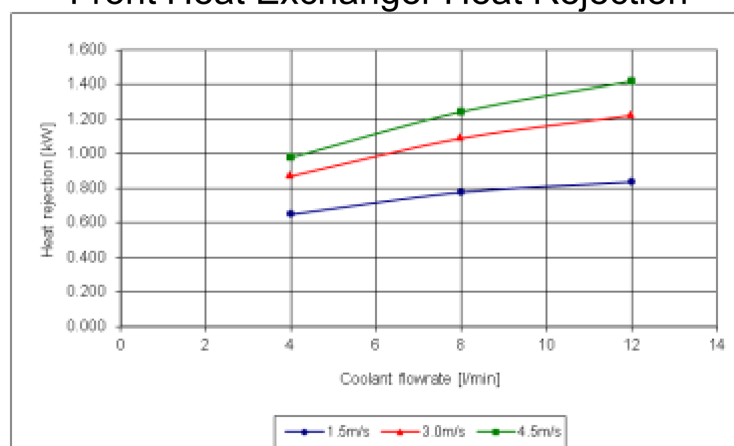


Liquid System Results

Measured Flow Rates

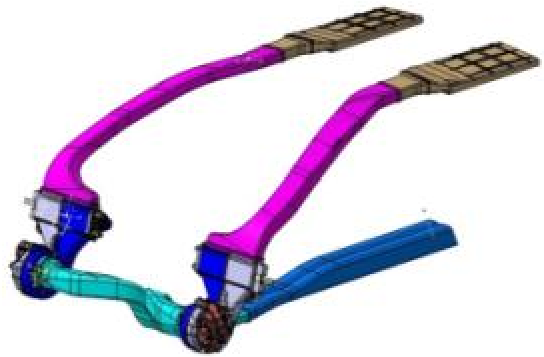
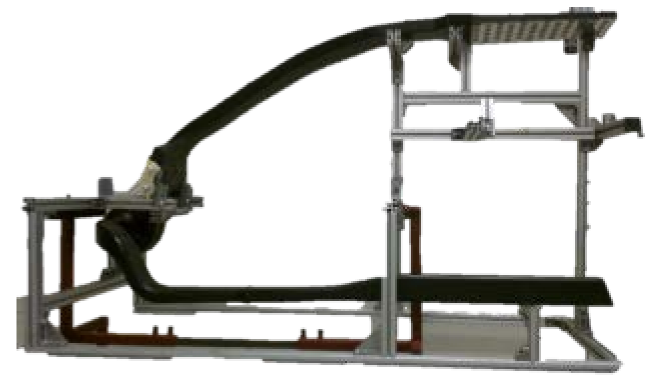
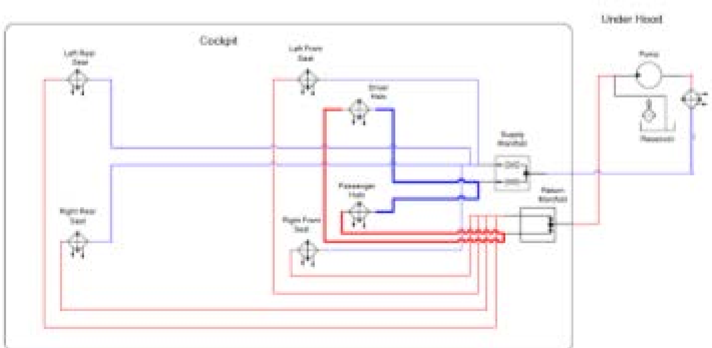
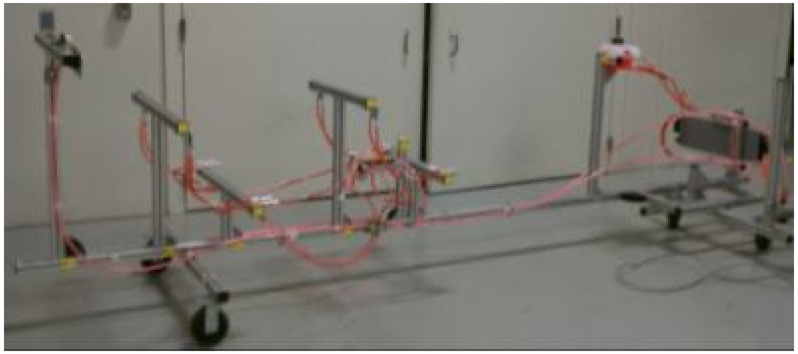
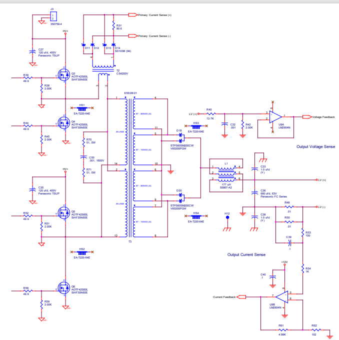
	Measured
Flow rate overall	2.4GPM
Flow rate to overhead system	1.2GPM

Front Heat Exchanger Heat Rejection



Technical Accomplishments – Design & Build

HCC Visteon
Halla Visteon Climate Control

	DESIGN	BUILD
Airflow System		
Liquid System		
Power System		

TE DEVICE DEVELOPMENT APPROACH

Thermoelectric Device Development

- Refine and optimize the Phase 2 device design for improved performance, durability, mass reduction and condensate management.
- Perform a detailed cost study of the device and identify target cost reduction actions to improve economical viability.
- Modify and improve manufacturing methods for improved throughput and quality.

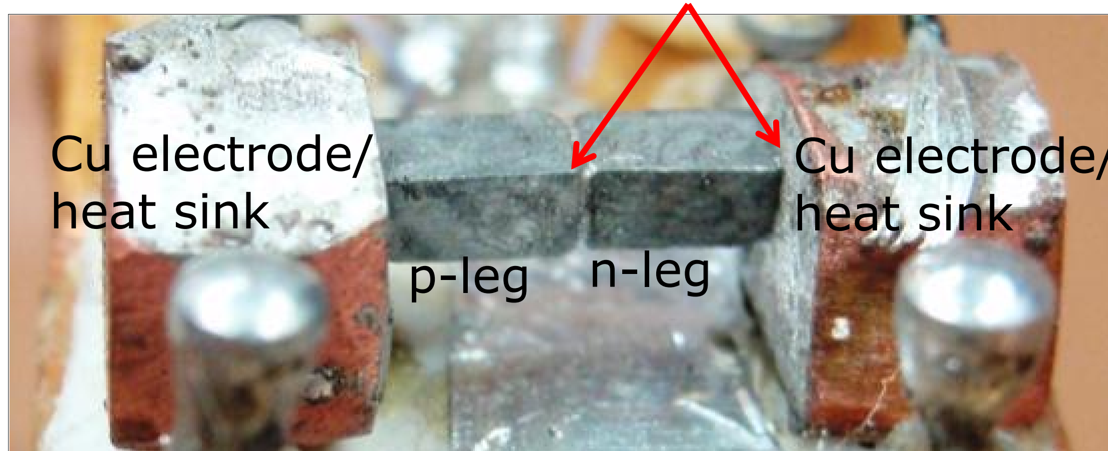
Advanced Thermoelectric Material Development

- Investigate the physical properties of porous materials and evaluate the performance of a single couple to validate the device level ZT. Coordinate with ZT::Plus to confirm performance measurements.

ADV. MATERIAL RESEARCH-OSU

- Individual TE property (κ,S,σ) testing of porous material samples shows an improvement in the ZT for both P-type & N-type samples. $zT = \frac{S^2\sigma}{\kappa} T$
- ZT_{device} Tests on the OSU material do not confirm the 3 parameter ZT values. $ZT_c^2 = 2\Delta T_{max}$
  - Attempts with different contact technologies to verify the performance of the new material were conducted unsuccessfully.

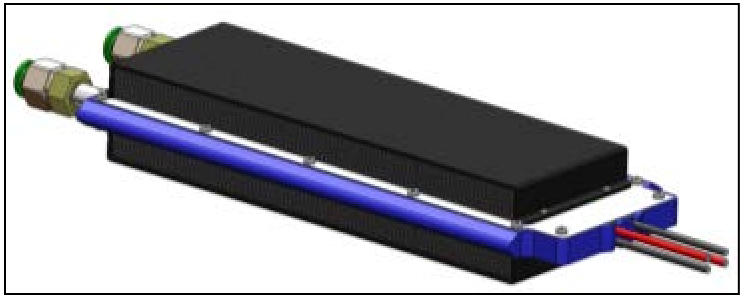
Peltier couple tests

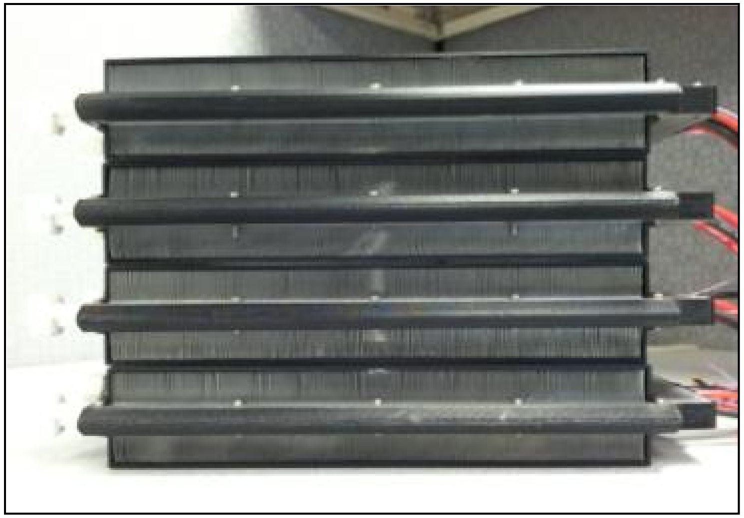


DESIGN AND BUILD OF DEVICE

Phase 3 Improvements:

- Air fin mass reduced 27% resulting in a equal reduction in thermal response time.
- Several durability improvements resulting in a 5X increase in the total number of thermal cycles to failure.
- Assembly processes improved build time and repeatability.

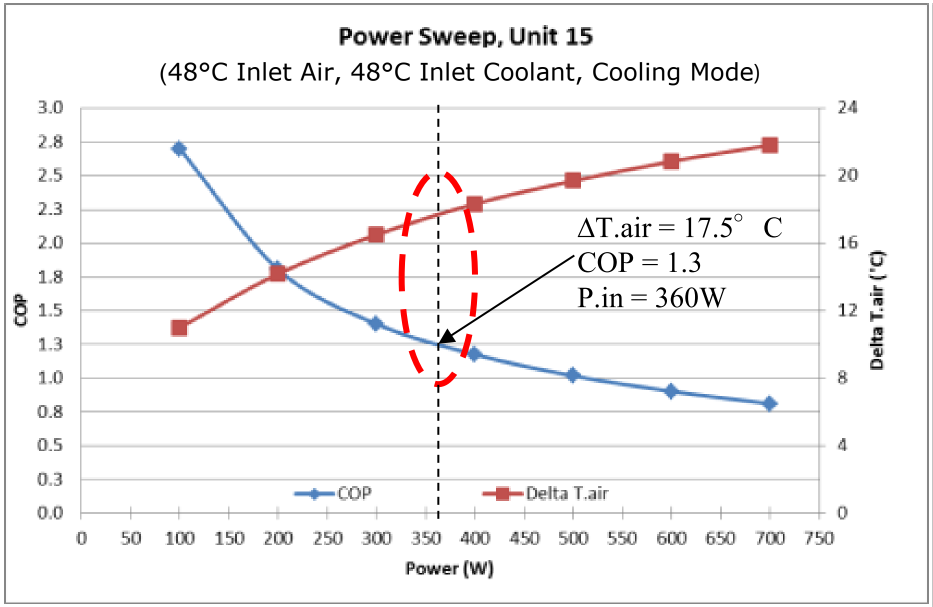


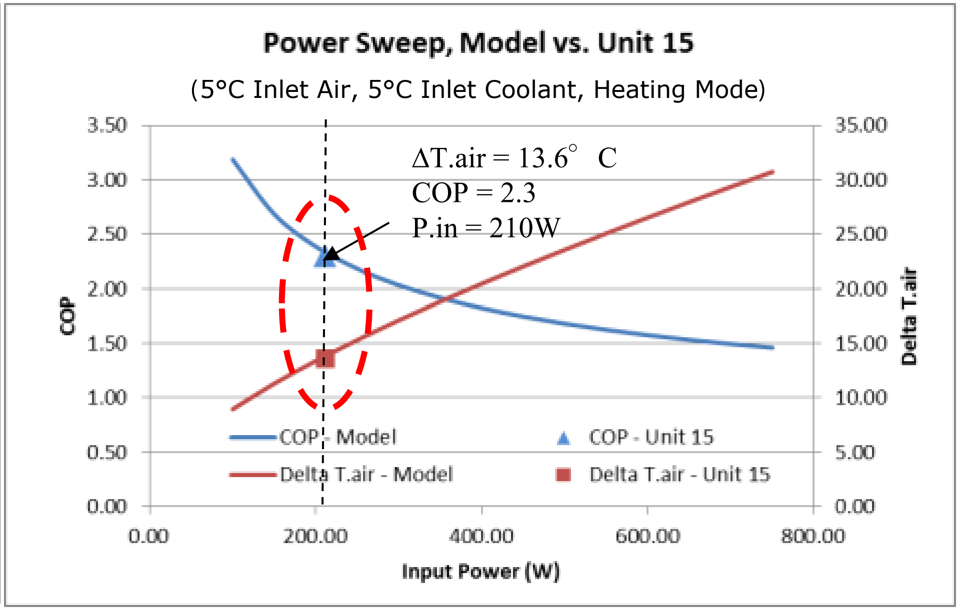


Phase 3 Devices (4 Units)

TEST AND MODELING CORRELATION

- Thermoelectric device – Program COP Targets:
  - Cooling Mode: COP of 1.3 with a ΔT.air of 17.5°C at 360W
  - Heating Mode: COP of 2.3 with a ΔT.air of 13.6°C at 211W





- Model matches ΔT within 1°C & COP within 0.14

GENTHERM INSPIRING EFFICIENCY

Technical Approach:
TE HVAC System Cost Study

Methodology

- Baseline assumptions and detailed cost analysis
  - Assume HEV to enable all-electric TE systems
- Zonal HVAC Feature Set:
  - 20k, 100k unit volumes cost basis
  - Hi-Series, Low-Series
- Zonal subsystem cost analysis:
  - Variable Cost, ED&T, Tooling, Mfg
    - Central HVAC
    - TE devices and seat climate
    - Overhead aux system
    - Balance of zonal TE system
    - Other modified systems

Technical Accomplishment:
Cost Study for Zonal System

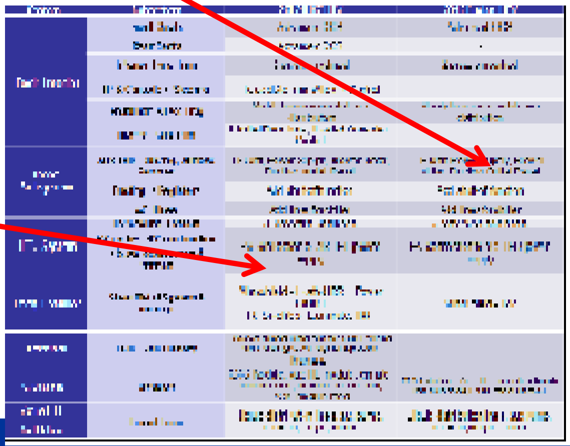
System Bill-of-Materials developed to study cost / weight / mfg. complexity

Luxury HEV

- Rows 1 & 2 advanced CCS
- Front row TE system
- Heated surfaces
- Zonal HVAC
- Zonal HVAC controls

Mainstream HEV

- Row 1 advanced CCS
- Front row TE system
- Zonal HVAC
- Zonal HVAC controls



Collaborations and Project Coordination

- Ford Motor Company:
  - Prime Contractor
  - Vehicle OEM
  - Systems Integrator
- Halla Visteon Climate Control:
  - Climate System Tier-1 Hardware and Controls
  - Power Electronics for TE systems
  - Zonal HVAC Integrator
- NREL:
  - Occupant Comfort Modeling / Testing
  - Ancillary Loads analysis
- Gentherm:
  - Advanced Thermoelectric Device and Module Development
  - Climate-Controlled Seat Module and Integration
  - Production Thermoelectric Materials Scale-Up and Manufacturing
- Ohio State University:
  - Advanced Thermoelectric Materials Research (Task completed September 2012)

Broad industry, government, academia collaboration with expertise in all aspect of the project

Remaining Critical-Path Activities for FY13 and FY14

FY13 (4Q12 – 3Q13)

- Complete installation of TE HVAC system and analysis equipment into test vehicle
- Wind tunnel and field testing performance of TE HVAC system
- Assess measured occupant thermal comfort and HVAC system energy consumption vs modeling prediction
- Commercialization assessment of TE HVAC system
- Vehicle demonstration for DOE & CEC

FY14 (4Q13)

- Prepare final report

Summary

- **Relevance**:
  - Climate control systems are a large auxiliary load on the powertrain and energy optimization can result in overall vehicle fuel economy improvement
- **Approach**:
  - Project focus is on developing methods to optimize climate system efficiency while maintaining occupant comfort at current levels using new technology, architecture, and controls approaches
- **Technical Accomplishments**:
  - On target to meet Phase 4 milestones and end-of-project deliverables
  - System architecture design study completed, advanced TE materials research results encouraging, TED liquid-to-air device results on-track, thermal comfort modeling predictions validated by test results
- **Collaborations**:
  - Cross-functional team working well together. Good mix of skills and resources to address the technical tasks in this project.
- **Future Directions**:
  - Continue to progress towards a vehicle demonstration of the technology

Acknowledgements

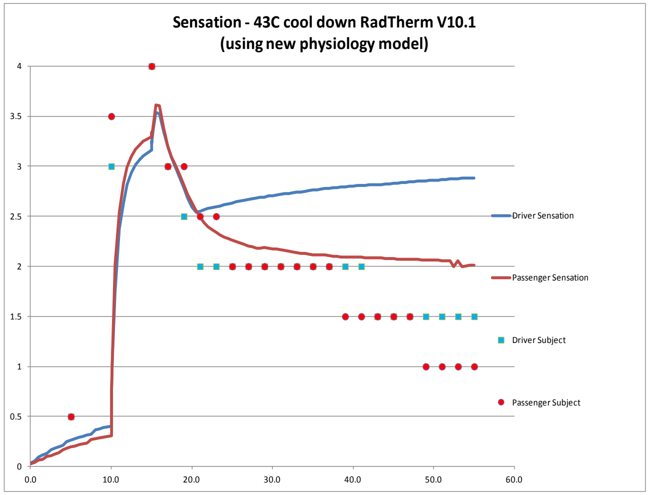
- We acknowledge the US Department of Energy and the California Energy Commission for their funding support of this innovative program

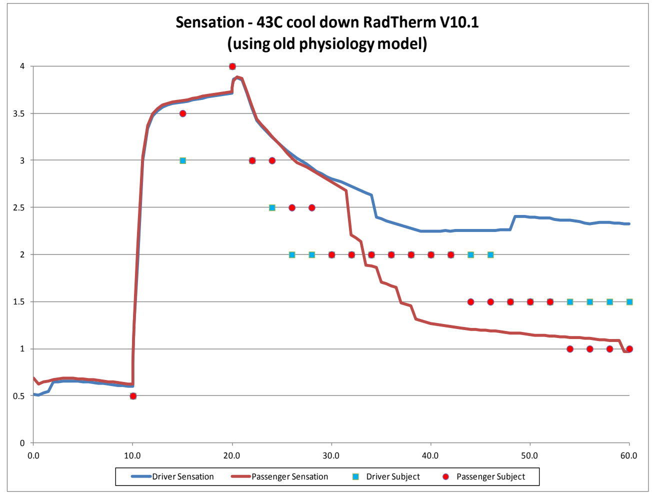
- A special thank you to John Fairbanks (DOE-EERE), Rhetta DeMesa (CEC), and Carl Maronde (NETL) for their leadership

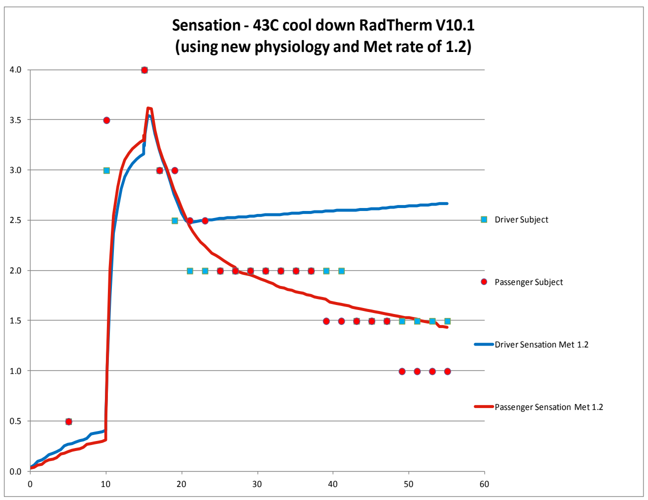
- Thanks to the teams at Ford, Visteon, NREL, Gentherm, and Ohio State University for their work on the program

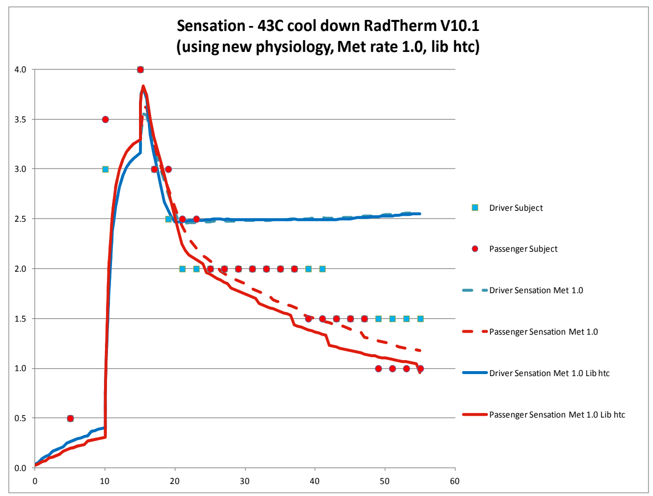
Technical Back-up Slides

Comfort Model Correlation Study Summary









Detailed Phase 4 Timeline