Energy Efficient HVAC system for Distributed Cooling/Heating with Thermoelectric Devices

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General Motors - Vehicle Engineering Center

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Project ID # ACE048

Overview

Timeline

- Start date – November 2009
- End date – July 31, 2013
- Percent complete – 50%

Budget

- Total funding: $9,097,593
  - Government* share: $4,548,796 (DOE obligations thru March 2012: $2,098,584)
  - Contractor share: $4,548,797
- Expenditure of Gov't funds in
  - FY11: $1,362,075 (10/10-9/11)
  - FY12: $736,509 (10/11-current)

Barriers & Targets

- Early stage of development for thermoelectric (TE) automotive HVAC devices (reliability concern)
- TE coefficient of performance > 1.3 to cool and > 2.3 to heat
- Reduce HVAC energy by > 30%

Partners

- Interactions / collaborations
  - *University of California – Berkeley:* Thermal Comfort testing & modeling
  - *Delphi Thermal Systems:* HVAC component development
  - *University of Nevada – Las Vegas*: Thermoelectric materials research
- Project lead – *General Motors*

* Thank you to the California Energy Commission and the DOE Vehicle Technologies Program for their support and funding of this project

Relevance

Primary DOE goal to use TE HVAC for distributed cooling/heating

- Reduce by at least 30% of the "billions of gallons" the fuel used to maintain occupant comfort through the localized use of TE technology while maintaining occupant comfort and safety.
- Develop TE HVAC components with a coefficient of performance > 1.3 for cooling and > 2.3 for heating, then integrate & test as a reliable system in an eAssist Buick LaCrosse and an extended range electric Chevrolet Volt.
- Develop a Thermal Comfort model and CAE tool to predict the occupant physiological response to localized heating and cooling through human subject testing – Key to balance and speedy execution of stratified thermal systems.

Secondary DOE solicitation goal to improve efficiency of TE generators

- Develop new thermoelectric materials for engine waste heat recovery applications (to provide power TE HVAC climate loads)

Milestones

2011 Through Quarter 1 2012

- Climatic Wind Tunnel tests for warm/cold ambient occupant comfort demonstrate occupant preference for reduced localized airflow velocity – April 2011
- “UCB Comfort Model update released” key milestone completed – April 2011
- Specifications and initial algorithms for components and controls complete – December 2011
- Vendor Intrepid Control Systems contracted to integrate control of TE components and vehicle interface – Feb 2012
- Faurecia* comfort seating system installed in eAssist Buick LaCrosse – March 2012

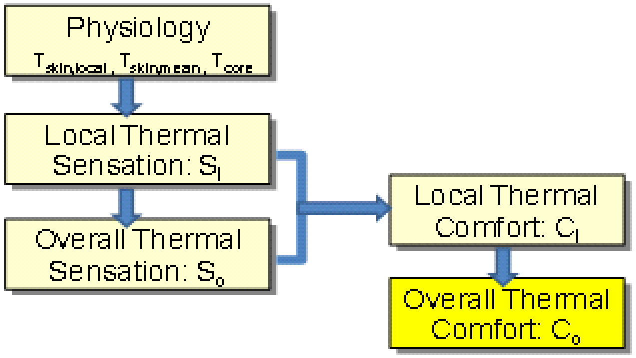
* Faurecia is not involved in TE material development or TE integration

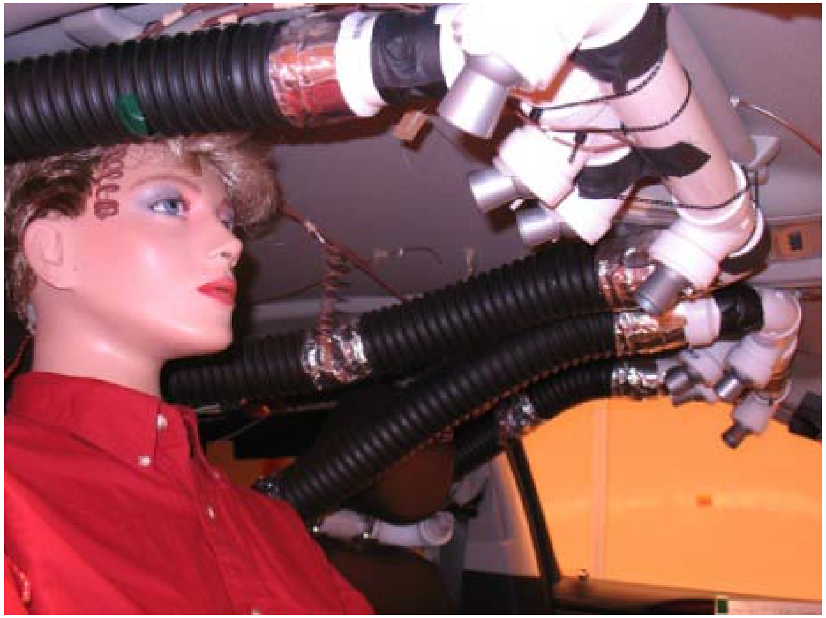
Approach and Strategy

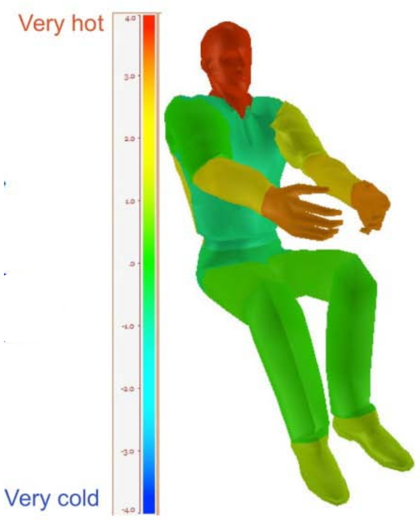
- **Task 2.1 Applied Research**: Develop Thermal Comfort model of human responses to potential locations for distributed heating & cooling
- **Task 2.2 Exploratory Development**: Develop the initial prototype HVAC components and evaluate on bench & demo vehicle (Milestone – Identify initial set of locations for distributed system)
- **Task 2.3 Advanced Development**: Develop final prototype HVAC components and evaluate on bench – show COP achievable (Milestone – 1. Identify final set of locations for distributed system and 2. Estimate Coefficient of Performance for TE components)
- **Task 2.4 Engineering Development**: Integrate final local HVAC components into demo vehicle, configure HVAC and Vehicle control system to optimize system performance – Complete vehicle testing to demonstrate limits of cabin thermal stratification (window fogging and dynamic mixing distraction risk).
- **Waste Heat Recovery Research**: Develop new thermoelectric generator material systems (concurrent with tasks 2.1 - 2.4) to *produce electrical power* for the TE HVAC system

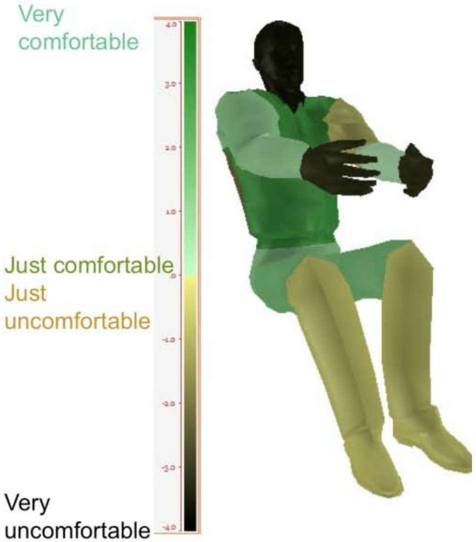
Technical Accomplishment

- Revisions to the Human Thermal Comfort model for localized cooling and heating correlate well with subjective and 16 segment thermal manikin vehicle evaluations (previous)
- "UCB Comfort Model update released" key milestone completed 4/26/2011
- "Identify final set of HVAC locations" key milestone completed 4/29/2011



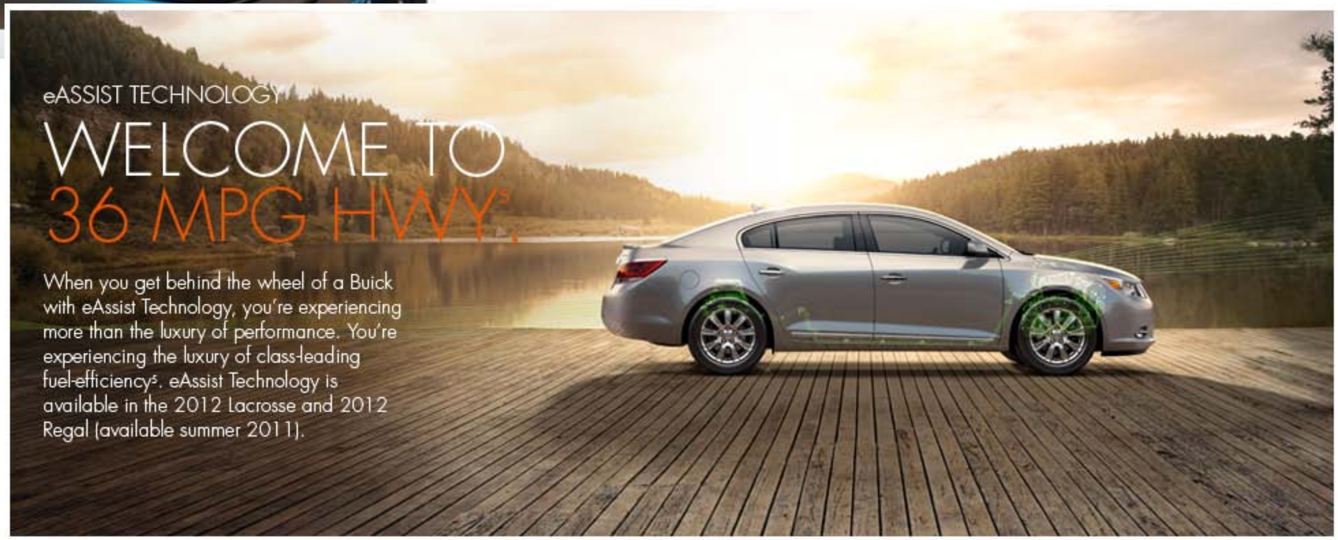






Technical Accomplishment - Continued

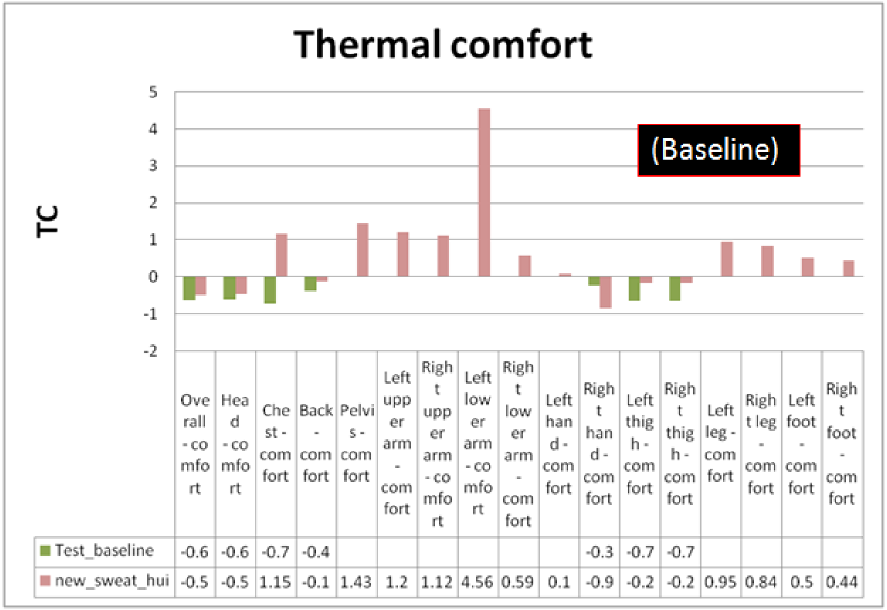
- Team criteria lead to selection of an eAssist Buick LaCrosse for final demonstration (previous). Vehicle and occupants have been modeled for virtual thermal comfort evaluation.



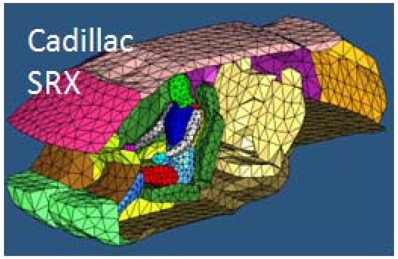
Technical Accomplishment (cont.)

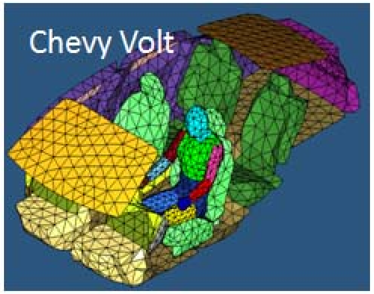
- CAE thermal comfort tool released compares favorably with actual tunnel test data (baseline case to right ->)

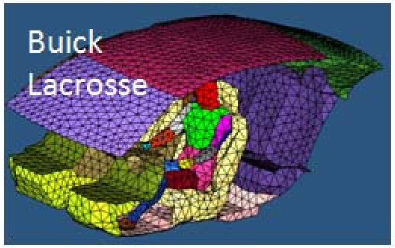
- First three of six vehicles implemented into the PC-based CAE tool – this enables thermal comfort engineering a broad distribution



	Overall - comfort	Head - comfort	Chest - comfort	Back - comfort	Pelvis - comfort	Left upper arm - comfort	Right upper arm - comfort	Left lower arm - comfort	Right lower arm - comfort	Left hand - comfort	Right hand - comfort	Left thigh - comfort	Right thigh - comfort	Left leg - comfort	Right leg - comfort	Left foot - comfort	Right foot - comfort
Test_baseline	-0.6	-0.6	-0.7	-0.4							-0.3	-0.7	-0.7				
new_sweat_hui	-0.5	-0.5	1.15	-0.1	1.43	1.2	1.12	4.56	0.59	0.1	-0.9	-0.2	-0.2	0.95	0.84	0.5	0.44

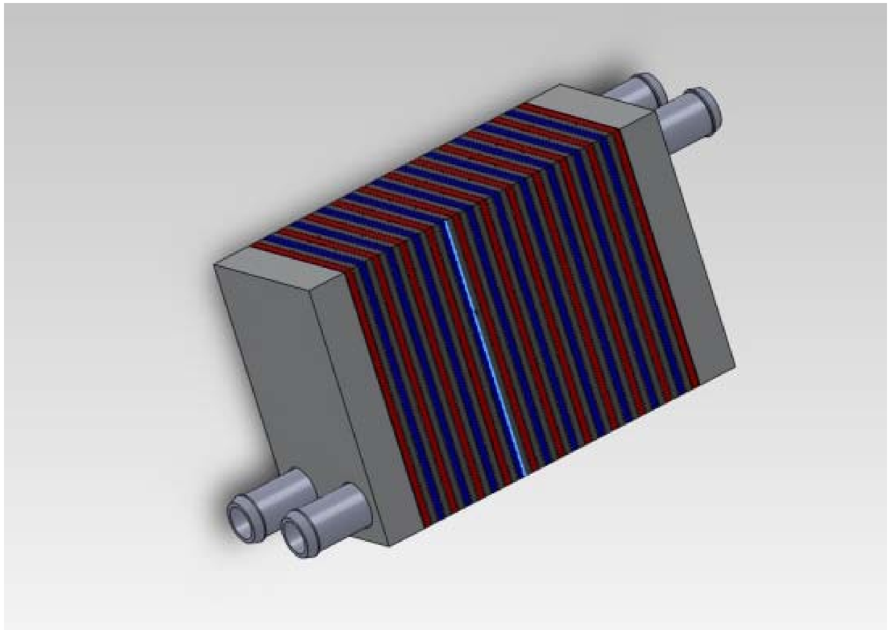






Technical Accomplishment (cont.)

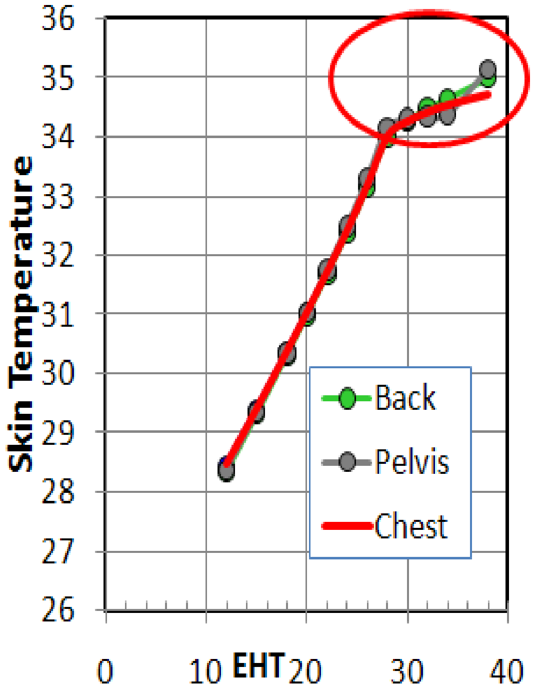
- Initial TE Design Concept for Chevrolet Volt Heater using a Plate and Frame Exchanger System
- Geometry of TE unit conforms with current production Positive Temperature Coefficient resistive unit.
- Preliminary testing of second design concept shows a COP of ~1.7 prior to optimization



Technical Accomplishment (cont.)

– Incorporated the most recent published data about sweat distribution on human body into the physiology portion of the Thermal Comfort model, improving the predicted skin temperatures in warm conditions now working to understand the effect with clothing variation.

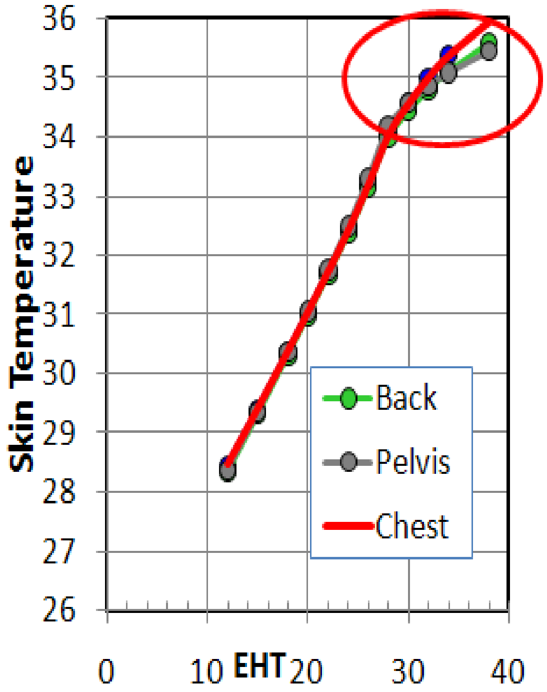
Simulation results with the old sweat distribution



Sweat distribution (SKINS.txt)

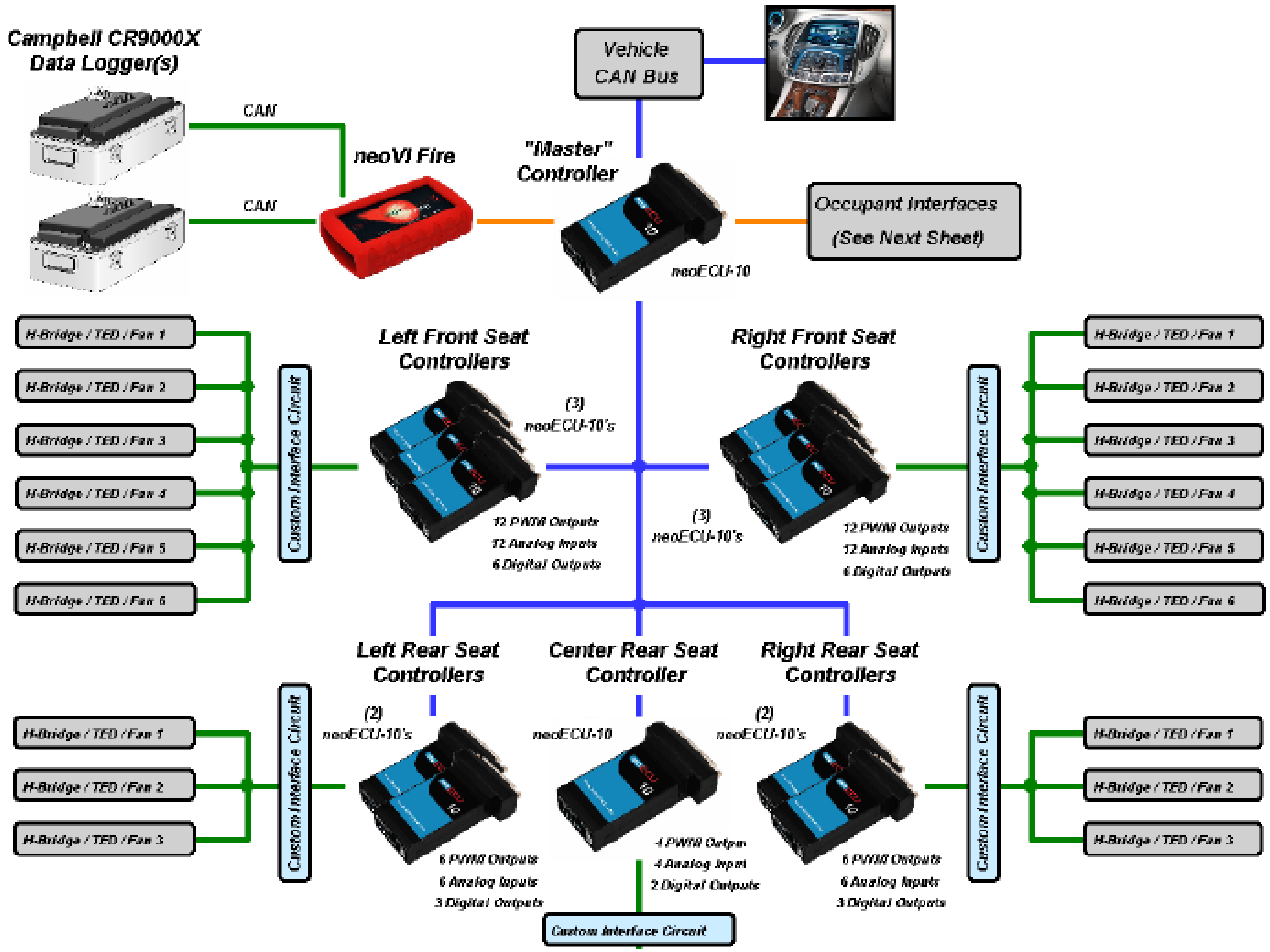
	Old	new
head	0.081	0.083
chest	0.146	0.052
back	0.129	0.079
pelvis	0.206	0.113
l-upper-arm	0.051	0.029
r-upper-arm	0.051	0.029
l-lower-arm	0.026	0.021
r-lower-arm	0.026	0.021
l-hand	0.0155	0.047
r-hand	0.0155	0.047
l-thigh	0.073	0.098
r-thigh	0.073	0.098
l-calf	0.036	0.091
r-calf	0.036	0.091
l-foot	0.0175	0.051
r-foot	0.0175	0.051
sum	1.000	1.000

Simulation results with the new sweat distribution



Technical Accomplishment (cont.)

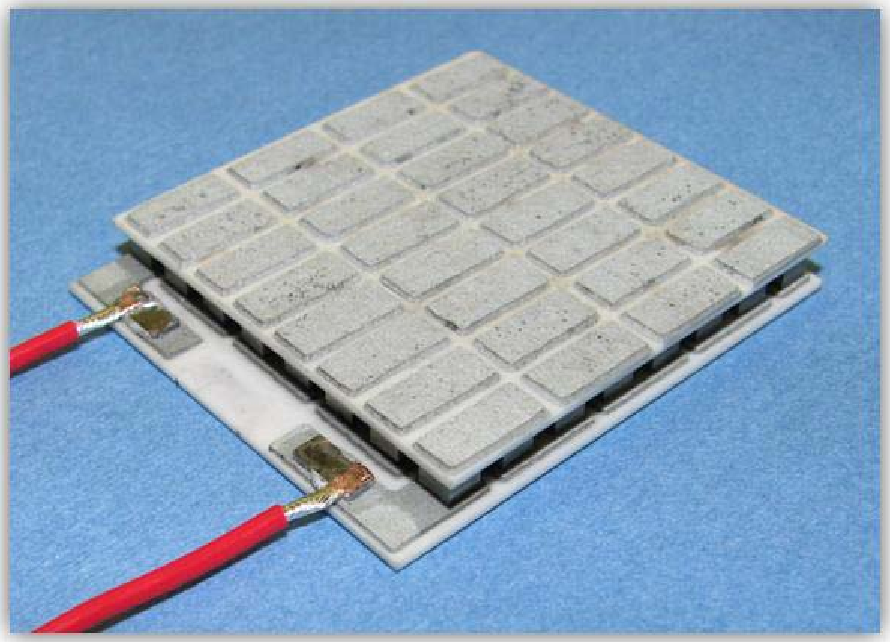
– "Specify control strategy" key milestone completed 12/19/2011



Technical Accomplishment (cont.)

Waste Heat Recovery Research Progress

– Progress made in process developments for TE modules – details consolidated in ACE_081 with PI Meisner



Collaboration and Coordination

GVE
GLOBAL VEHICLE ENGINEERING
Vehicle Integration
System Controls
T

DELPHI
TE Component Design
Climatic Wind Tunnel Testing
Vehicle Instrumentation

faurecia
Modify Passenger Seating to
Optimize Thermal Comfort

GM R&D
CAE Modeling
Project Management
TE Material Research

marlow industries, inc.
Thermoelectric Innovation Through Research
TE Module
Development

INTREPID CONTROL SYSTEMS, INC.
Global provider of innovative vehicle network and embedded tools since 1994.
Contractor for Prototype TE device
control system

Berkeley
UNIVERSITY OF CALIFORNIA
Human Subject Testing
Comfort Model Enhancement

OAK RIDGE
National Laboratory
TE Material
Measurement

UNLV
TE Material Research
Computational Research Methods

Proposed Future Work

- **Complete Phase 2 activities by Sept. 30, 2012**
  - Vehicle Build/Instrumentation Complete – June 5, 2012
  - Climatic Tunnel Test Complete – June 29, 2012
  - Go/No-Go: Can final set meet the performance objectives?
- **Begin Phase 3 activities on August 1, 2012**
  - Commercialize design of new components – look back at liquid cooling decision and enhance imperative tradeoff
  - Test and evaluate final components and vehicle integration
  - Component Qualification Report
- **Develop localized strategy for Chevrolet Volt**
  - Initial vehicle level test with high output coolant heater for defrosting and defogging performance to reduce the climate control induced variation in battery operating range between -10 to 32^{o}C (14 to 90^{o}F)

Summary – TE HVAC Project

- Relevance - The climate control system is the largest vehicle parasitic load with strong FE and mass impact.
- Approach - Optimize localized HVAC components using a refined Thermal Comfort model. Develop TE components that provide efficient localized heating & cooling of occupants. Manage thermal stratification/fogging risk with central system operating energy
- Accomplishments – VTCE and personal computer tool refined to aid in evaluation of localized heat transfer. Control strategy developed for TE components
- Collaboration – UCB, Delphi, Faurecia, and GM meet frequently to refine daily activity. The UCB comfort tool integration allows rapid optimization of distributed HVAC components. GM developing TE material systems with UNLV and Marlow research.
- Future Direction
  - Commercialization of TE integrated system and further vehicle power train control system optimization
  - High Watt density cabin coolant heater development for efficient defrosting performance in a Chevrolet Volt

GM

Acknowledgements

The California ENERGY COMMISSION

DEPARTMENT OF ENERGY • UNITED STATES OF AMERICA

Technical Back-Up Slides

Specific Risks & Challenges

Our preliminary analysis shows a conflict for achieving the goals when the third goal is required:

- Reduce fuel used for occupant comfort by 30% by localized use of TE technology
- Thermoelectric devices/systems must be cost-competitive with currently used technologies and be produced on the scale needed for vehicle mass production.
- **Develop components COP_{cool}> 1.3 and COP_{heat}> 2.3**