Improving Energy Efficiency by Developing Components for Distributed Cooling and Heating Based on Thermal Comfort Modeling [ Thermoelectric (TE) HVAC ]

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Objectives - Relevance

Project Primary Goal: Integrate TE technology in a distributed cooling/heating climate control system

- Reduce fuel used for occupant comfort by 30% by localized use of TE technology
- Develop components COP_{cooling} > 1.3 and COP_{heating} > 2.3
- Integrate & test as a system in 5-passenger demonstration vehicle
- Integrate & test an extended range electric vehicle (Chevrolet Volt)
- Develop a model to predict occupant physiological response to transient localized heating and cooling
Objectives - Relevance

Project Secondary Goal: improve TE generators
  – Develop TE materials for engine waste heat recovery applications (to provide power TE HVAC climate loads)

2011 Objectives:
  – Comfort Model Enhancement and Validation
  – Climate System Efficiency metrics
  – Powertrain Mode operation impacts
Overview – The Challenge

TE devices in a traditional internal combustion engine vehicle utilize power at a cost of 0.3 mpg per 100 alternator watts, whereas a traditional AC compressor utilizes crankshaft power at 0.2 mpg per 100 crankshaft W.

Electric vehicles, in comparison, do not have a crankshaft advantage for Climate Control Power delivery.

TE devices in cooling mode obtain an average COP of 1.3 whereas a traditional AC compressor typically attains a COP greater than 2.0.

TE devices can be integrated into the vehicle more effectively than traditional HVAC heat exchangers, and thereby overcoming the above performance constraints.
Milestones – Technical Accomplishments

Through Quarter 3 2011

• Completed identification of initial set of components for distributed heating and cooling development – Mar. 31, 2010

• Complete build of mule vehicle with simulated TE devices for Thermal Comfort evaluation – Aug. 31, 2010

• Complete Design of Experiments for phase 1 testing of Mule and virtual vehicle – Nov 16, 2010

• Climatic Wind Tunnel tests for warm ambient occupant comfort evaluation demonstrate occupant preference for reduced localized airflow velocity – Dec 16, 2010

• Strategy and method to control distributed climate control system identified – March 10, 2011
Team Composition

- **DELPHI**
  - TE Component Design
  - Climatic Tunnel Testing
  - Vehicle Instrumentation

- **GM R&D**
  - TE Material Research
  - CAE Modeling
  - Project Management

- **Berkeley University of California**
  - Human Subject Testing
  - Comfort Model Enhancement

- **Faurecia**
  - Modify Seating to Optimize Thermal Comfort
  - Optimize Interior surfaces

- **US Department of Energy**
  - Funding
  - Project Oversight

- **UNLV**
  - TE Material Research
  - Computational Research

- **California Energy Commission**
  - Funding
  - Project Oversight
Approach/Strategy

• **Applied Research – Phase 1:** Develop Thermal Comfort model of human responses to potential locations for distributed heating & cooling
  – Identified potential locations for distributed HVAC components and measured their physiological and psychological effectiveness
  – Used automotive mockup in the UC-Berkeley environmental test chamber and mule vehicle in Delphi Climatic Tunnel to perform human subject testing
  – Update UC-Berkeley’s Thermal Comfort model as the “key component” of the Virtual Thermal Comfort Engineering (VTCE) computer-aided engineering (CAE) tool used by GM and Delphi Thermal Systems

• **Exploratory Development – Phase 2:** Develop the initial prototype HVAC components and evaluate on bench & mule vehicle
  – CFD and vehicle Design of Experiments (DoE) analysis
  – Functional intent component manufacturing and vehicle integration
  – Define control strategies and algorithms
  – Build eAssist LaCrosse with design intent localized TE components
Approach/Strategy (cont.)

- **Advanced Development – Phase 3**: Develop final prototype HVAC components and evaluate on bench
  - Optimize control system to balance comfort and consumption (engine mode)
  - Estimate HVAC system efficiency improvements, (central system mass reduction and vehicle thermal load reduction)
  - Commercialize TE components for future production application

- **Engineering Development – Phase 4**: Integrate final local and central HVAC components into demo vehicle and optimize system performance
  - Build advanced propulsion demonstration vehicle
  - Test and evaluate distributed HVAC system
  - Calculate expected customer efficiency gain
  - Deliver vehicle and final report to DOE/CEC

- **HVAC Material/Waste Heat Recovery Research – Phase 5**: Develop new thermoelectric generator materials (concurrent with phases 1-4) to produce power for the TE HVAC climatic loads
Technical Accomplishments and Progress

• Team selection criteria lead to the Cadillac SRX for the mule demonstration, and an eAssist Buick LaCrosse for final demonstration

• Vehicles and occupants have been modeled for virtual evaluation

• Test and simulation procedures for local distribution evaluation established jointly between UC-B, Delphi and GM
Technical Accomplishments and Progress (cont.)

- All phases of testing benefit from UC Berkeley thermal manikin evaluation; providing detailed localized comfort measurement with an absence of psychological influence
Technical Accomplishments and Progress (cont.)

- Revisions to the Human Thermal Comfort model for localized cooling and heating correlate well with subjective and 16 segment thermal mannequin vehicle evaluations.
- VTCE analysis guides localized component determination.
Technical Accomplishments and Progress (cont.)

• Thermal comfort human subject testing data from UC Berkeley’s environmental test chamber was used for GM’s VTCE tool validation.
Technical Accomplishments and Progress (cont.)

- Delphi’s Climatic Wind Tunnel testing used for emulated local spot cooling (September 2010)
- Conditioned air supply source installed in test vehicle, manifold distribution for rapid thermal variation and reconfiguration
- Mule Simulation report issued October 31, 2010

UC-B thermal maikin and human subjects used to evaluate spot cooling
Localized Spot Cooling in Tunnel Test Results – Breath temperature comparison at 25°C EHT

Improved comfort early in the drive cycle offers engine mode enhancement!
AC mass flow rate can be reduced by 30.7% by raising cabin air temperature from 22 C to 25 C.
Energy Balance

- Based on 4 kW baseline cooling load, 2.0 COP: 30% reduction in air mass flow results in 600 Watt crankshaft energy savings (1.0 mpg saving)
- Spot cooling used above requires about 70 alternator Watts (TED) per occupant at a 1.3 COP (0.2 mpg cost per occupant)
- Net Energy reduction assuming 2 occupants is about 460 Watts. (0.6 mpg saving net)
Collaboration and Coordination with Other Institutions

- **University of California – Berkeley:**
  Human subject testing & Thermal Comfort modeling enhancement

- **Delphi Thermal Systems:**
  HVAC component development and testing

- **University of Nevada – Las Vegas:**
  Thermoelectric materials computational research

- **GM Vehicle Engineering:**
  Vehicle requirements, system integration

- **General Motors R&D:**
  CAE tool development and TE materials research

- Human subject and Mule testing benefit from live participation between GM, Delphi and UC-B: better correlation between test phases via accurate procedure duplication and application of superior thermal comfort knowledge
Proposed Future Work

• Phase 2 activities began in May, conclude next March
  – CFD and vehicle Design of Experiments (DoE) analysis
  – Functional intent component manufacturing and vehicle integration
  – Metric Development for performance objectives
  – Define control strategies and algorithms to obtain integration efficiency (including engine mode)

• Develop localized strategy for Chevrolet Volt
  – Narrow the climate control induced variation in battery operating range between -10 to 32\degree C (14 to 90\degree 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

• Accomplishments – UC-B Thermal manikin aids correlation, VTCE tool refined to aid in evaluation of localized heat transfer. Mule testing validated optimal locations for TE components

• Collaboration – UC-B, Delphi and GM meet to refine daily activity. The UC-B comfort tool integration allows rapid optimization of distributed HVAC components. UNLV TE material research is essential for the components Delphi will build in phase 2.

• Future Direction
  • Control system hardware development to regulate system output for efficient thermal comfort
  • High Watt density cabin coolant heater development for efficient defrosting performance in a Chevrolet Volt