Improving the Efficiency of Light-Duty Vehicle HVAC Systems using Zonal Thermoelectric Devices and Comfort Modeling

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Project Relevance / Objectives

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

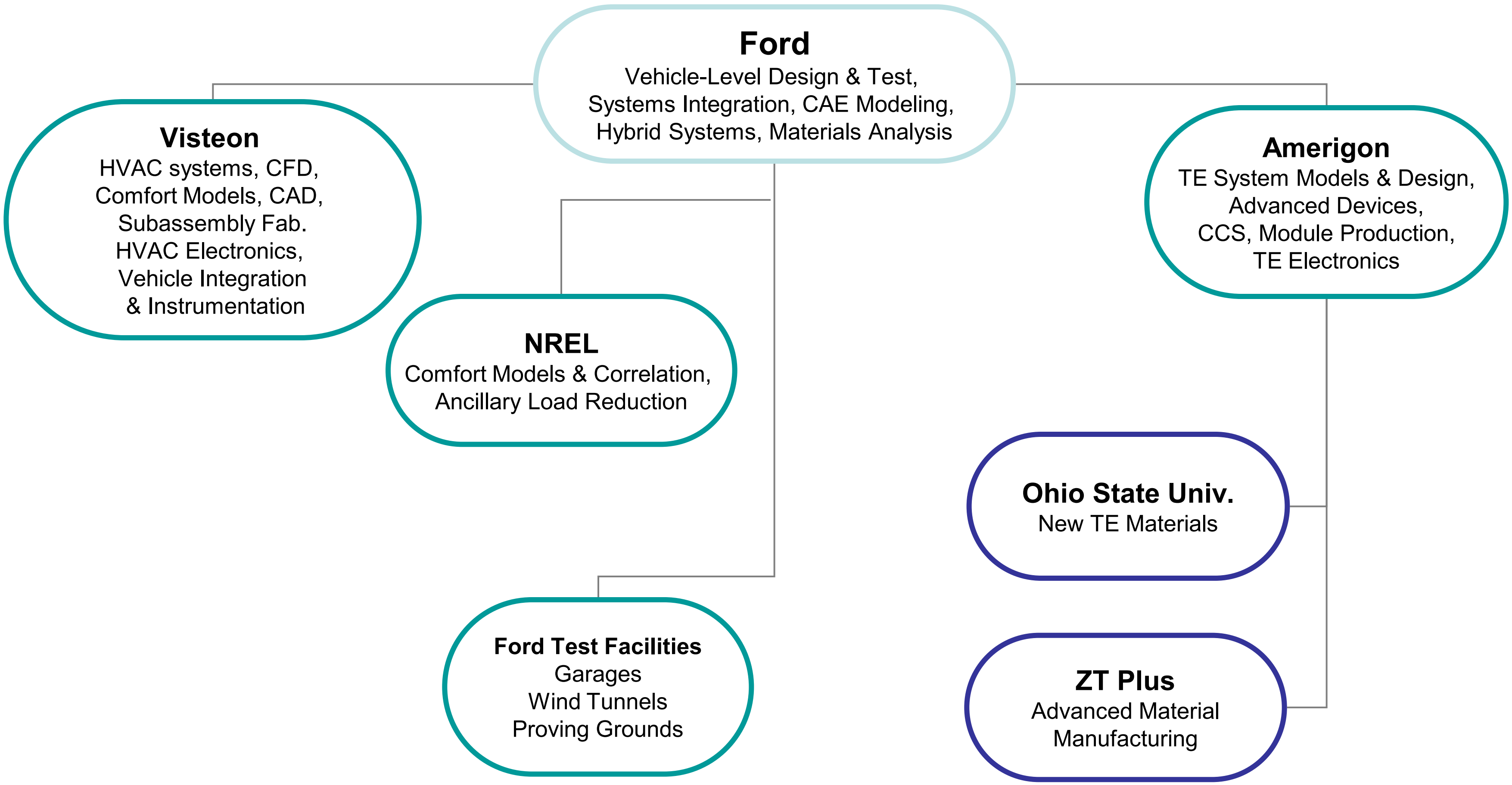
Program Objectives:

- 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

FY2011 Objectives:

- Select a TE HVAC architecture to fully evaluate and design
- Model system behavior and comfort response of alternative architecture
- Estimate energy savings from use of TE HVAC architecture
- Design & test HVAC elements and control strategies using vehicle buck
- Develop candidate n-type TE material; design proof-of-principle TE HVAC module
- Develop detailed systems-level component requirements and specifications

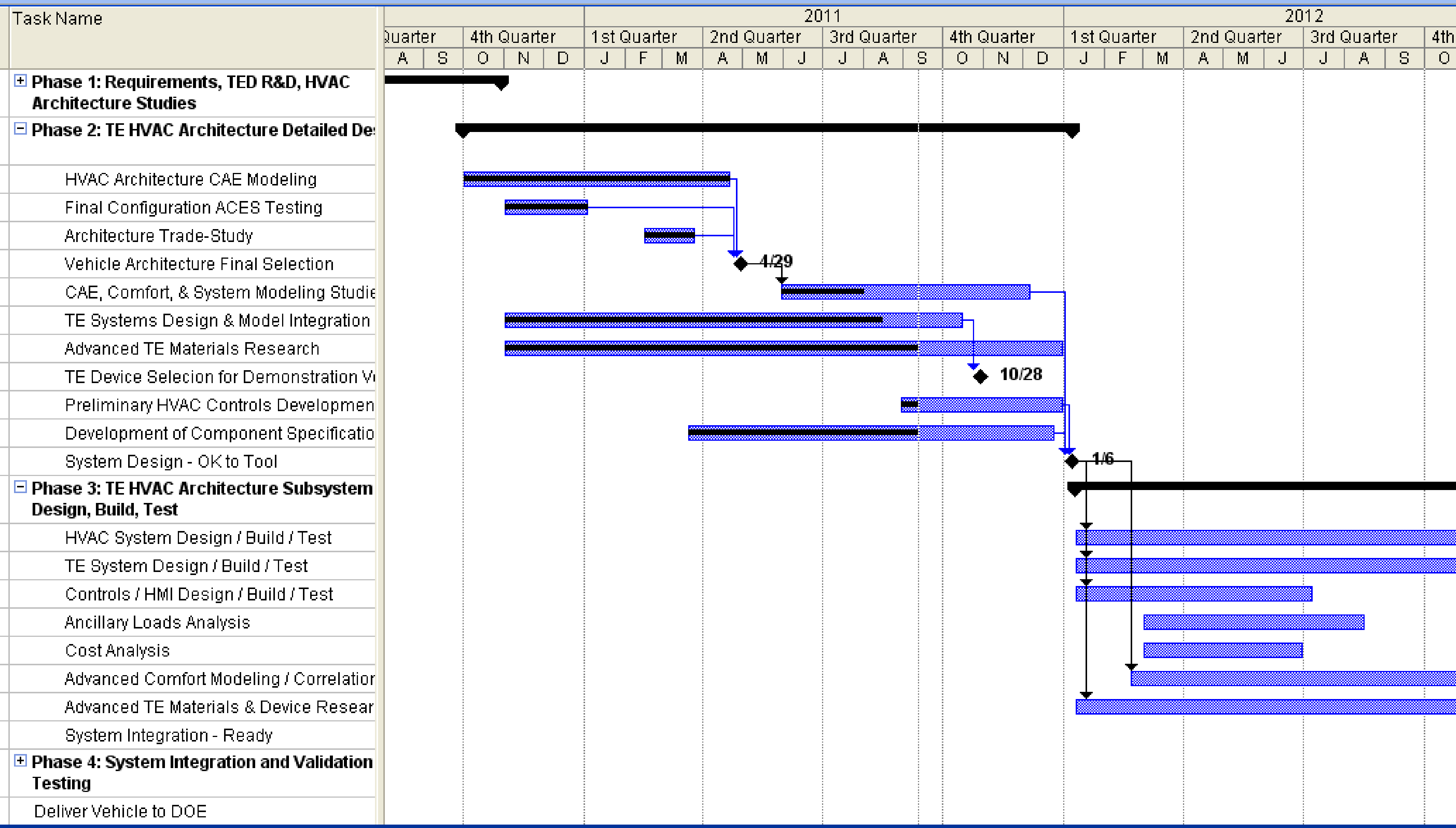
Team Structure



Technical Approach

- 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

Project Timeline



Phase 2 Task Overview

System-level HVAC architecture design

- Develop test conditions & occupant comfort metrics
- Determine vehicle-level performance acceptance criteria
- Assess and enhance thermal comfort tools
- Develop and assess HVAC system architectures through detailed CAE analysis
- Develop models to assess baseline HVAC and TE HVAC system power budget and fuel consumption

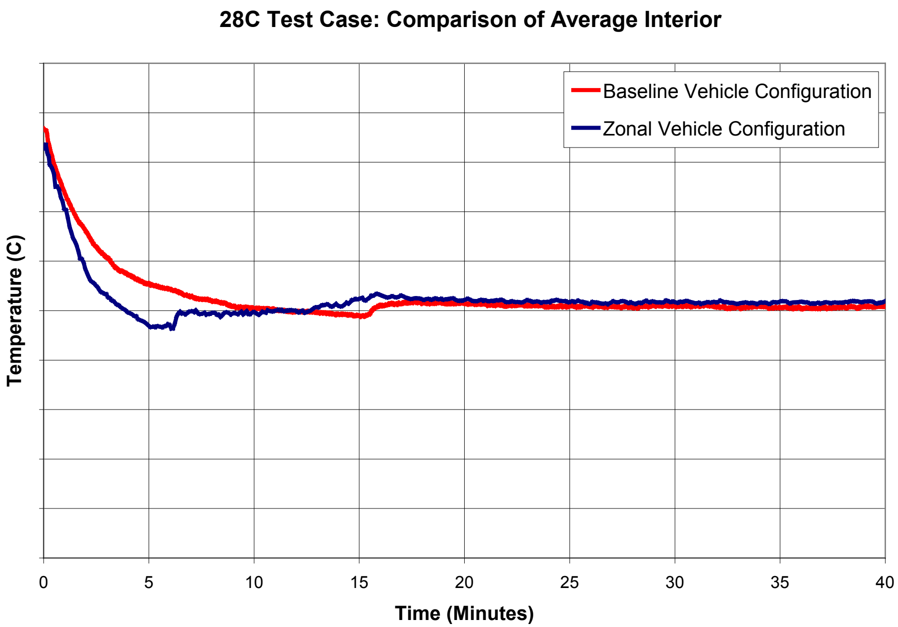
TE HVAC system and materials research

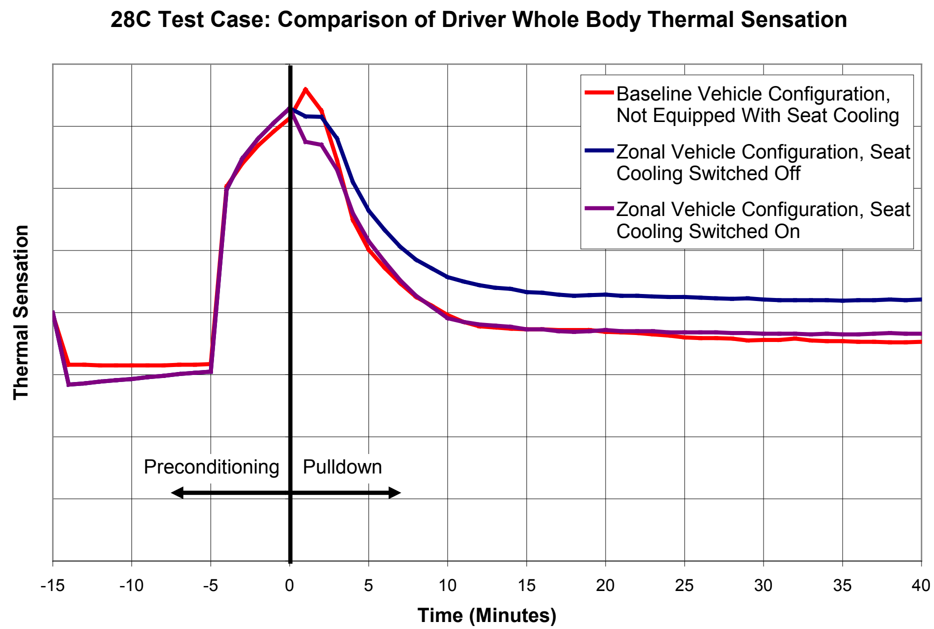
- Initiate pilot-process development for p-type TE materials research
- Begin n-type TE materials research
- Extend TE systems model & build liquid-to-air prototype TED hardware for validation studies

Success Criteria

- CAE modeling of TE HVAC architecture indicates required comfort levels can be achieved
- System modeling shows the TE HVAC architecture can achieve reductions in energy usage from baseline vehicle
- Research plan for TE materials and devices shows a specific path to deliver a technically and commercially viable TE system

Assessment of a Zonal-HVAC Equipped Vehicle





- Computational Fluid Dynamics (CFD) assesses the temperature performance and airflow characteristics of zonal-HVAC equipped vehicles.
- Thermal Comfort/Sensation modeling will predict whole body thermal response for all test cases and vehicle configurations.
- These modeling tools analyze and compare the performance characteristics of zonal-HVAC equipped vehicles to the baseline vehicle to ensure equal or better performance.

Air Chamber Evaluation System (ACES) – Half Buck

ACES Chamber

Previous Setup – Man in Box

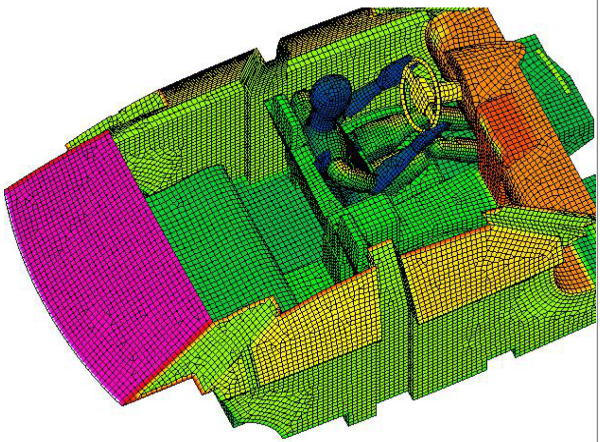
New Setup – ½ Buck

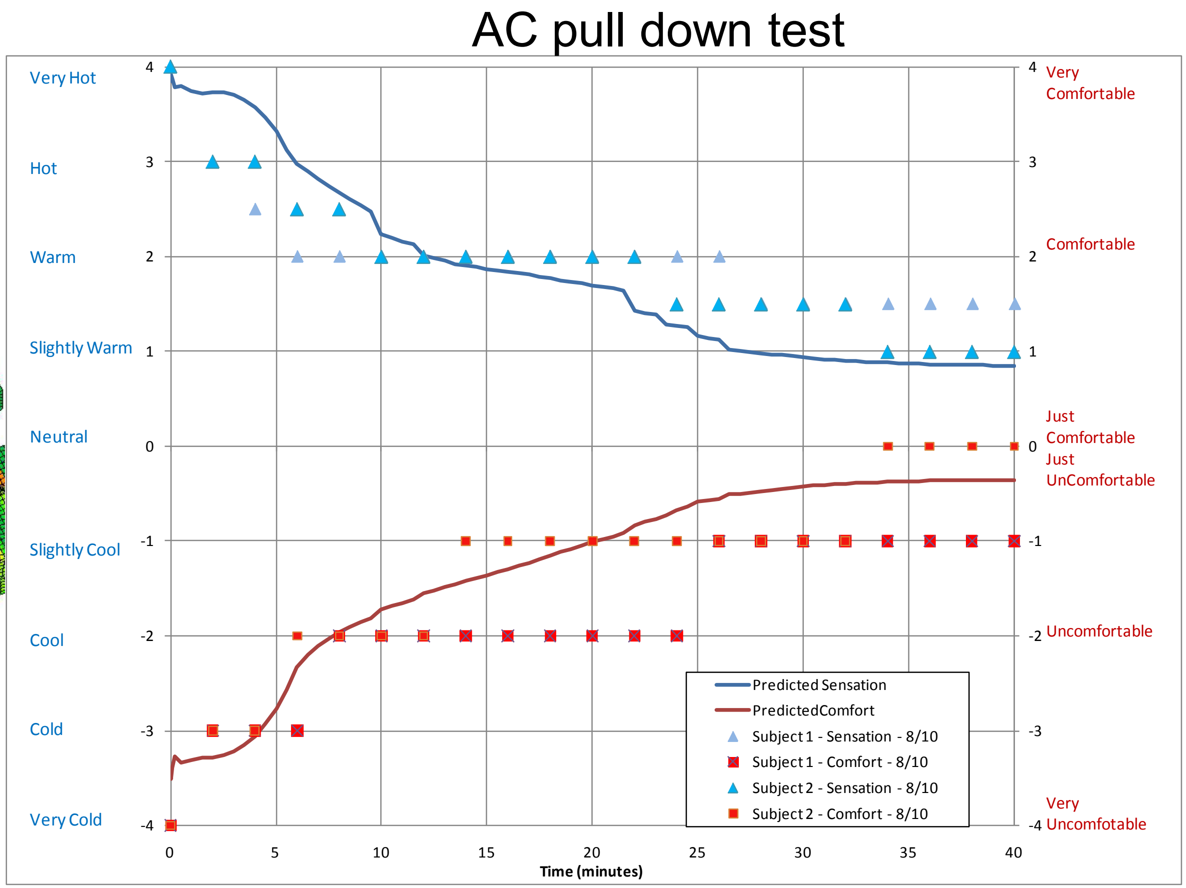
- Fusion ½ Buck has been installed into the ACES System for the next level of evaluation
- Capability to independently control various distributed HVAC elements has been incorporated
- ACES setup is being used to validate CAE Comfort Model predictions and will include Wind Tunnel Testing conditions as a baseline
- Testing to start end of 3Q2011

½ Buck in ACES

Thermal Sensation/Comfort Analysis Options

- Evaluating multiple modeling approaches
- AcuSolve CFD / RadTherm / UCB path show good potential for prediction of thermal sensation and comfort

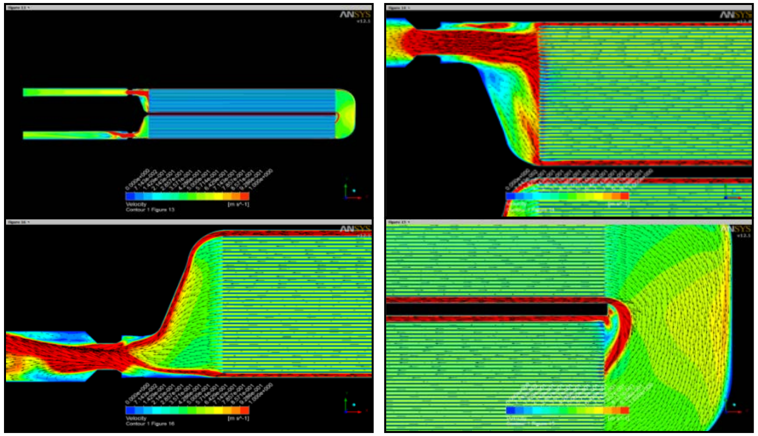




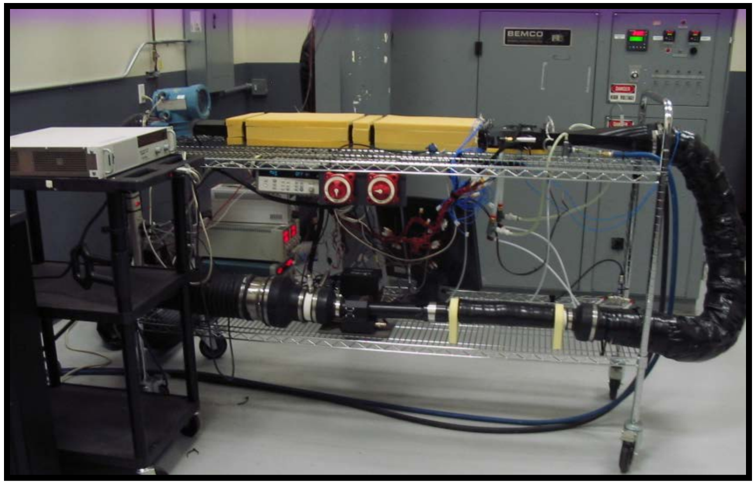
Thermoelectric Device Design: Modeling, Design & Testing

Current Efforts –

- Updated Phase 1 CAE model to size and develop Phase 2 designs in support of initial vehicle level requirements.
- Model used to understand parasitic loses in potential design architectures and down select design options.
- Custom high performance liquid heat exchanger has been designed and is being fabricated for the Phase 2 device.
- Calorimeter instrumentation upgraded to provide more data on the design and improve accuracy.

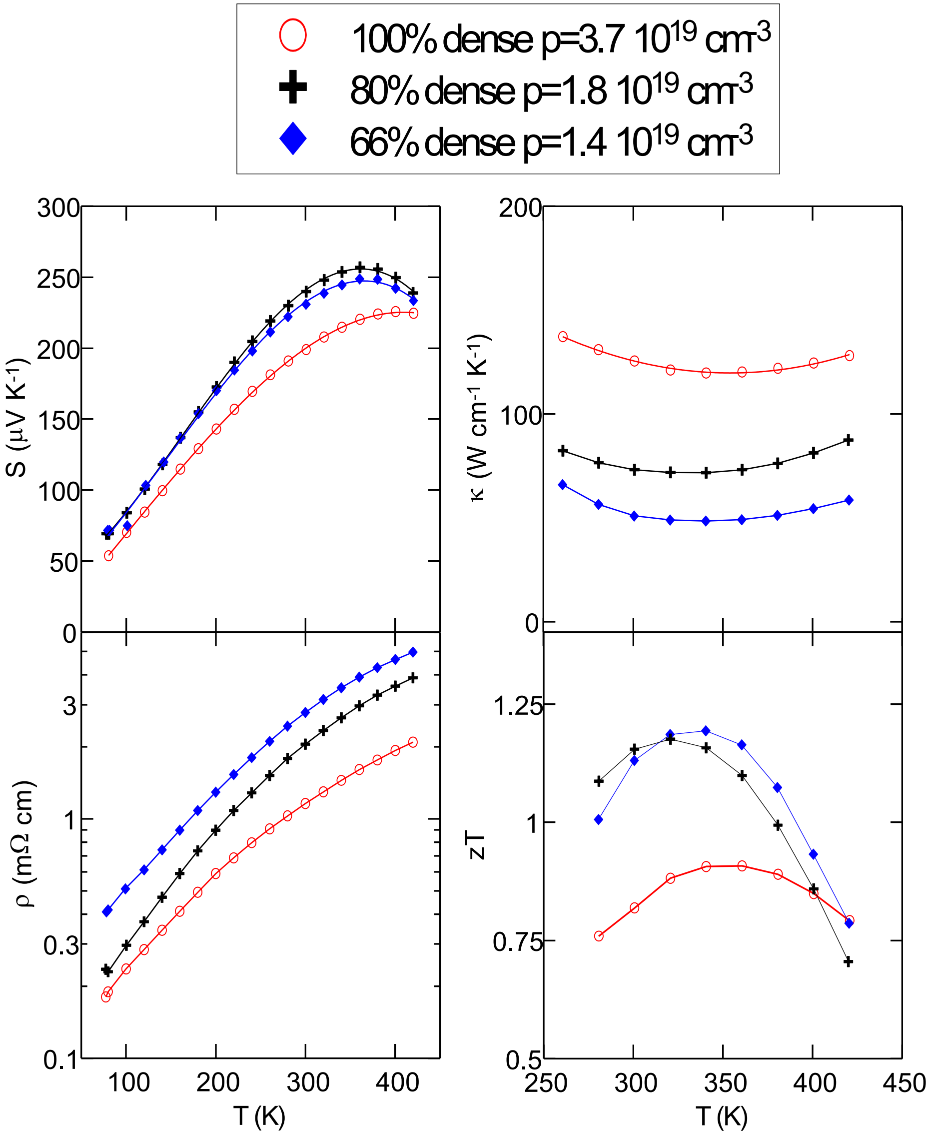


Liquid HEX CFD



TED Calorimeter Apparatus

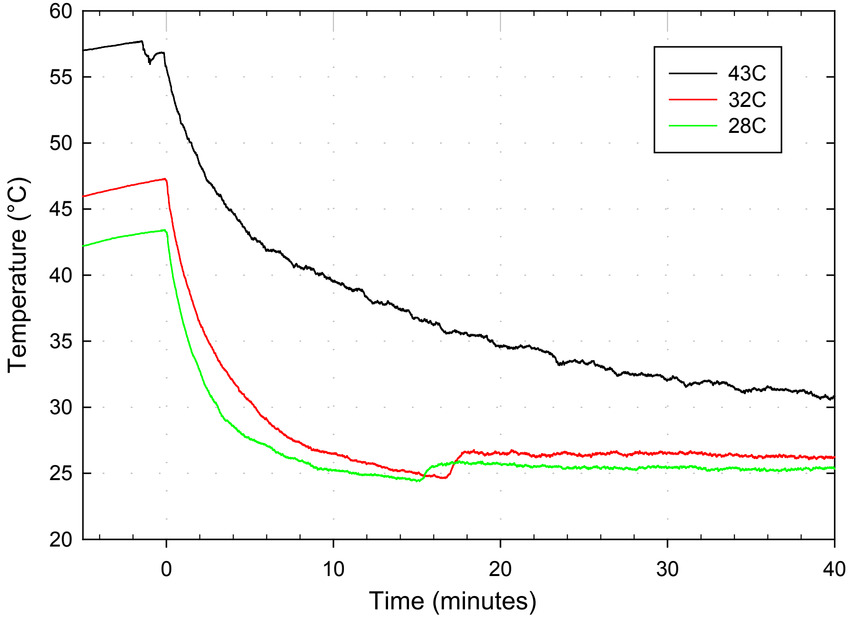
Porosity increases zT of p-type $Bi_{0.5}Sb_{1.5}Te_3$



- p-type research efforts focus on reduction in thermal conductivity to increase ZT and optimal doping to improve power factor
- Lab-scale tests reveal peak zT level ~ 1.2 (p-type)
- n-type materials are being evaluated to determine optimal doping and processing strategy
- This effect will be scaled to practical thermoelectric alloys and synthesis routes

Baseline Vehicle Testing: HVAC Performance & Thermal Comfort

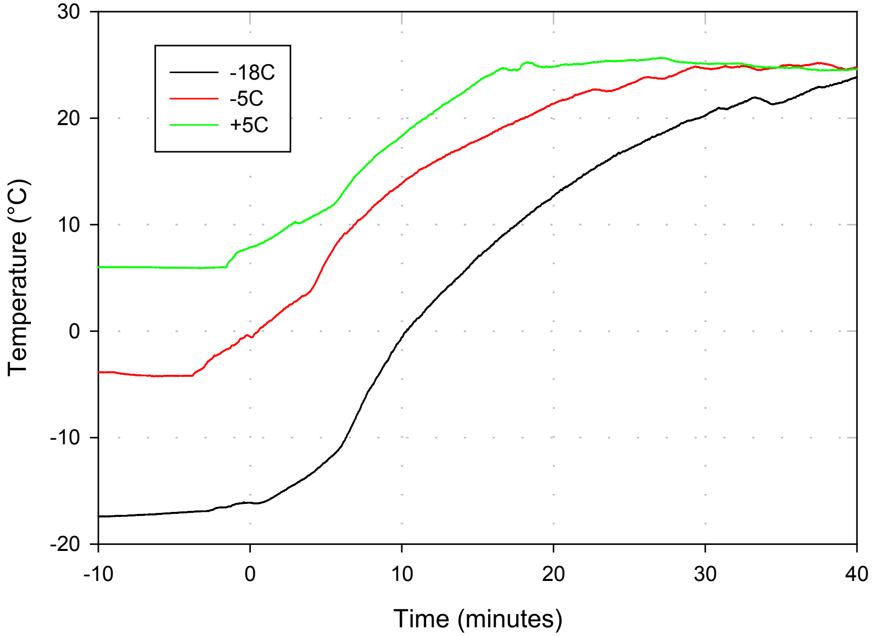
Hot Ambient Testing



Thermal Sensation / Comfort

43°C: 6 / –1.5 (16 min)
32°C: 5 / +0.5 (12 min)
28°C: 5 / +1.0 (8 min)

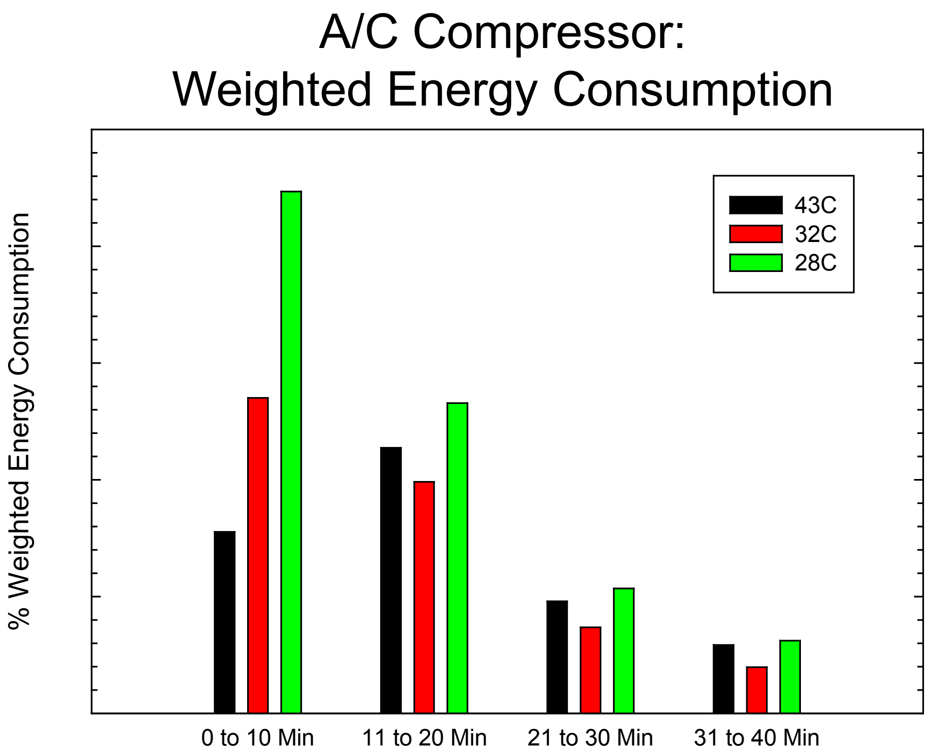
Cold Ambient Testing

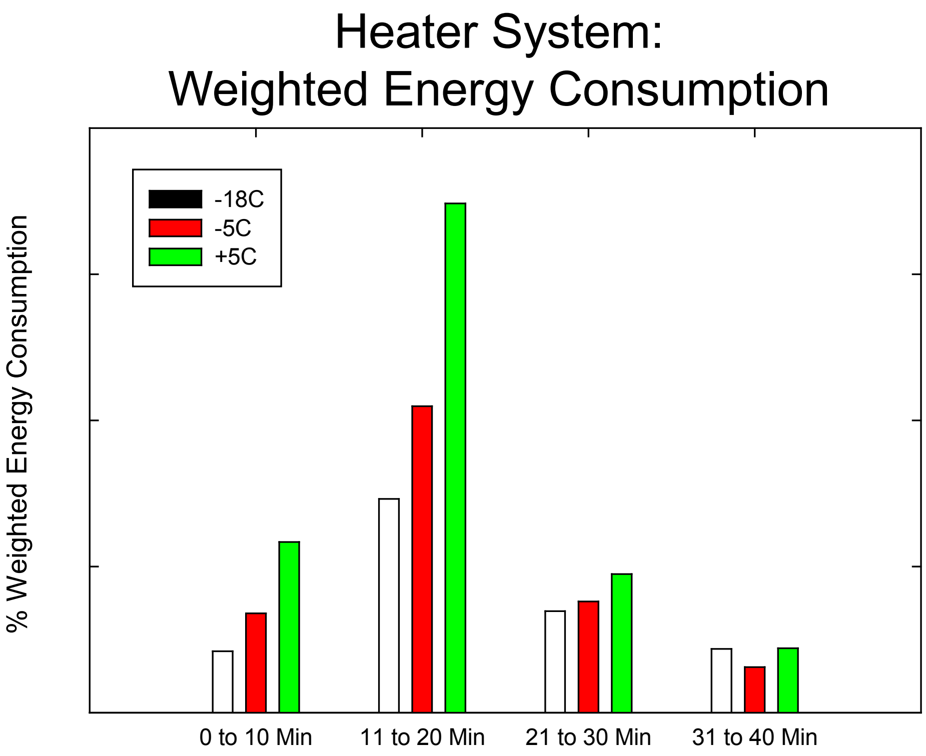


Thermal Sensation Comfort

-18°C: 4 / -1.0 (17 min)
- 5°C: 4 / -1.0 (12 min)
+5°C: 4 / -1.0 (8 min)

Modeled Energy Usage





- Cooling energy consumption is initially high due to large demand on blower and A/C compressor
- Heating energy consumption is delayed due to delay in heater core warm-up

Summary

- HVAC system energy consumption is substantial (but mostly off-cycle) and must be considered when developing technology for improving overall real-world vehicle efficiency
- A Zonal TE HVAC architecture becomes more viable as vehicles evolve towards higher levels of electrification and engineering attribute criteria accounts for quantitative occupant-based comfort metrics
- Our current 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
- Project is on target to meet Phase 2 milestones and deliverables by the end of 4Q11
- Hardware design-freeze will occur early 1Q12 and subsystem design, build, and test is planned to be completed by this time next year

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