Progress Towards Development of a High-Efficiency Zonal Thermoelectric HVAC System for Automotive Applications

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Disclaimer

Relevance / Objectives

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

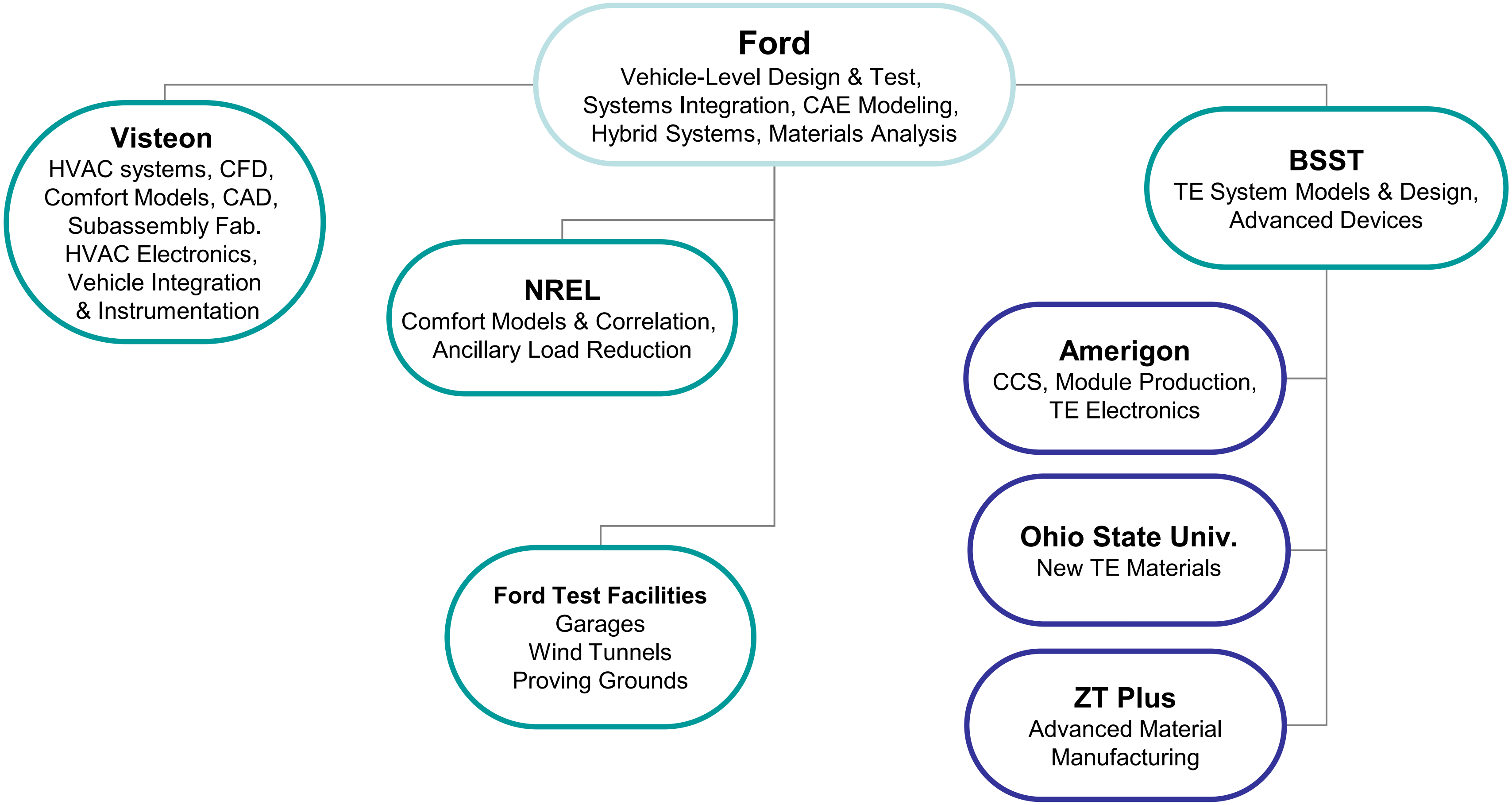
Program Objectives:

- 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

FY2010 Objectives:

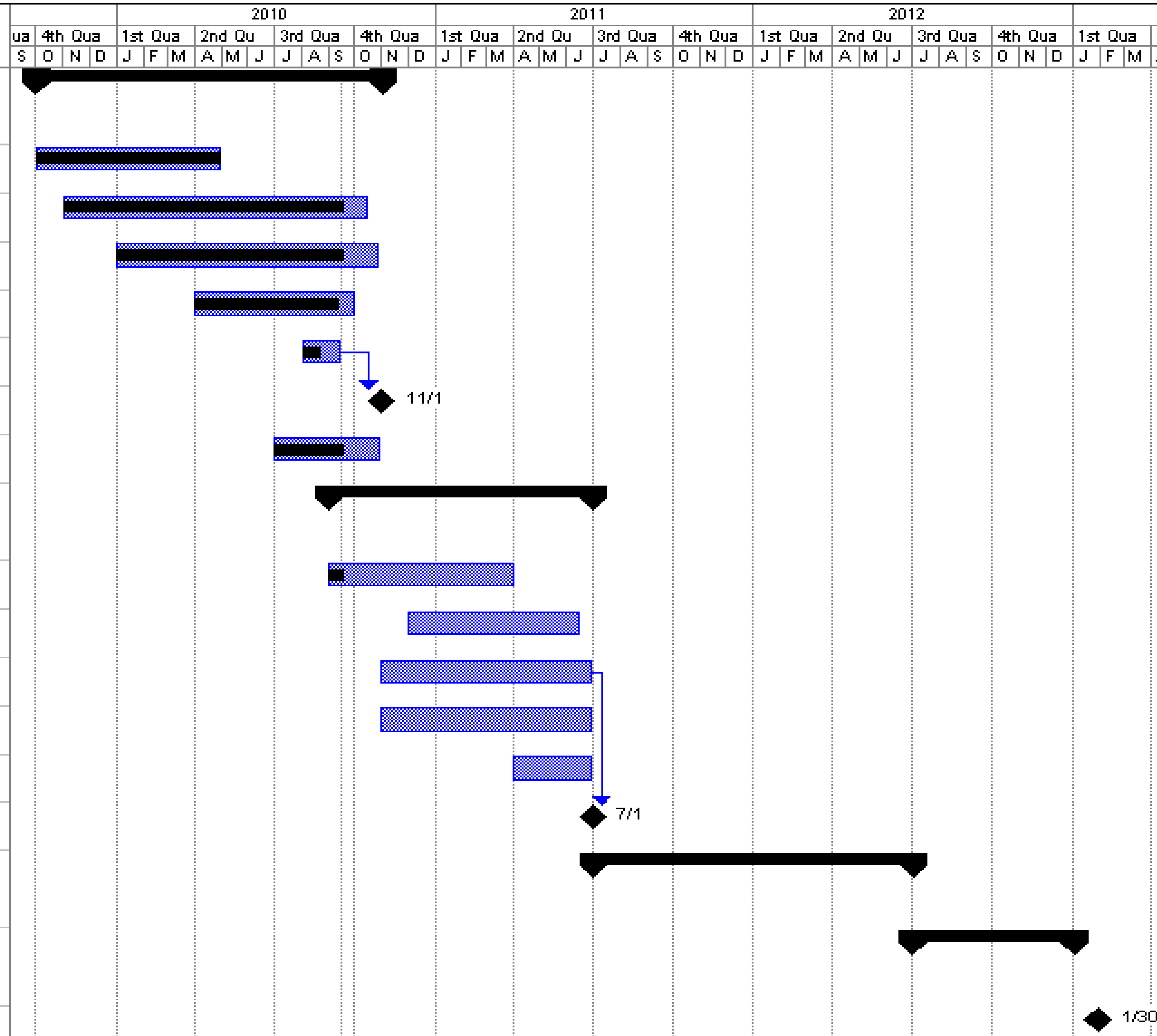
- Select vehicle and establish baseline performance
- Determine test and analysis methods / tools
- Establish comfort and vehicle performance criteria & targets
- Determine and study candidate HVAC system architectures
- Select an architecture to fully evaluate and design

Team Structure



Project Timeline

ID	Task Name
1	Phase 1: Requirements, TED R&D, HVAC Architecture Studies
2	Requirement Development & Modeling
3	TE Device Development & Modeling
4	Advanced TE Materials Research
5	Baseline Vehicle Testing
6	HVAC Architecture Studies
7	HVAC Architecture Selection
8	Systems Modeling for FE & Power Budget
9	Phase 2: TE HVAC Architecture Detailed Design
10	Architecture CAE Modeling
11	CAD Studies
12	TE Systems Design & Model Integration
13	Advanced TE Materials Research
14	HVAC Controls Development
15	System Design - OK to Tool
16	Phase 3: TE HVAC Architecture Subsystem Design, Build, Test
24	Phase 4: System Integration and Validation Testing
29	Deliver Vehicle to DOE



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

Phase 1 Tasks – Applied Research

System-level HVAC architecture development

- 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 advanced TE materials research
- Develop TE systems model & prototype hardware for validation studies

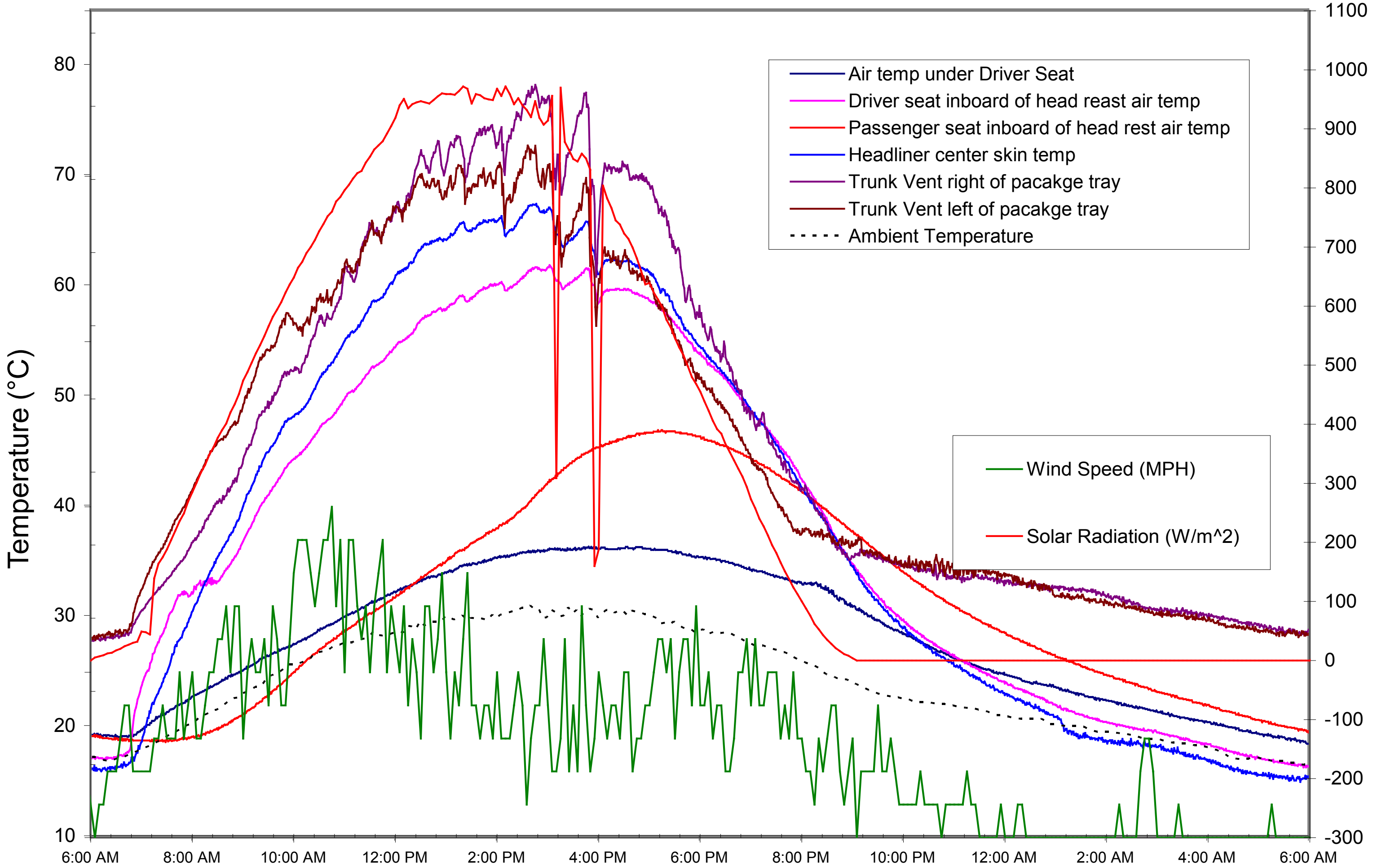
Success Criteria

- 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

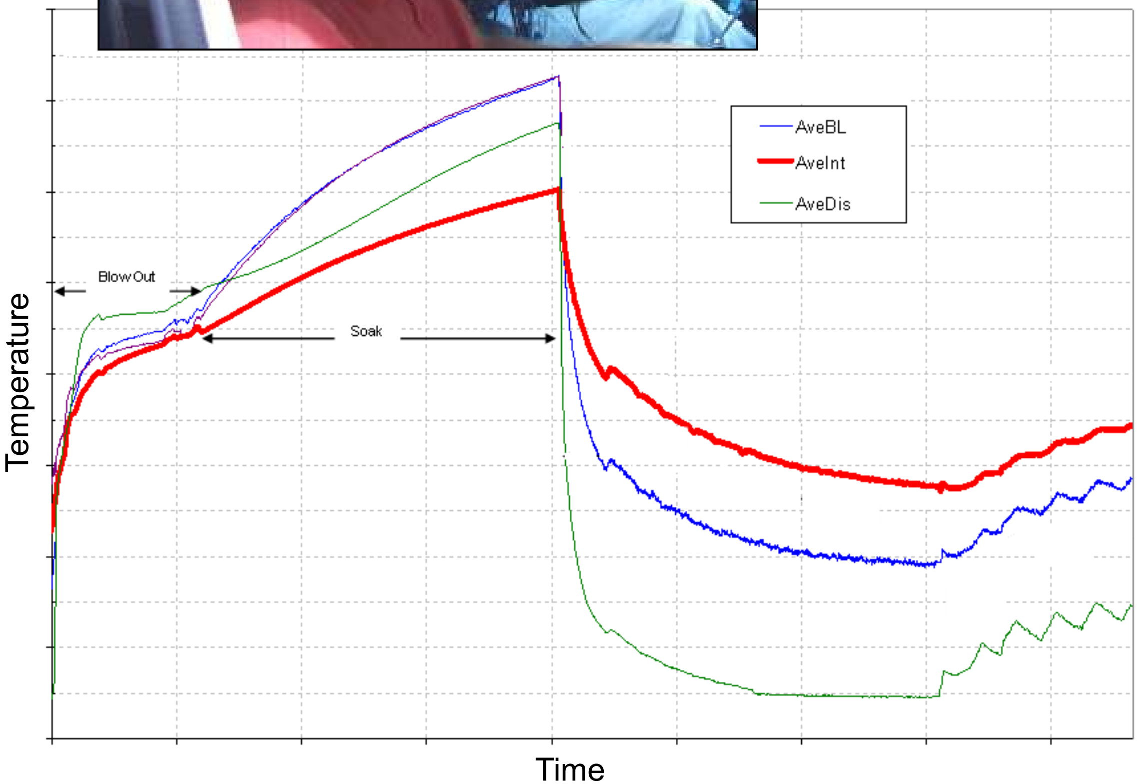
Baseline Vehicle Climate System Performance Testing

- Validate soak parameters for outdoor and wind tunnel testing
- Establish baseline variability for individual vehicle components
- Understand baseline energy consumption during representative hot and cold-weather operation

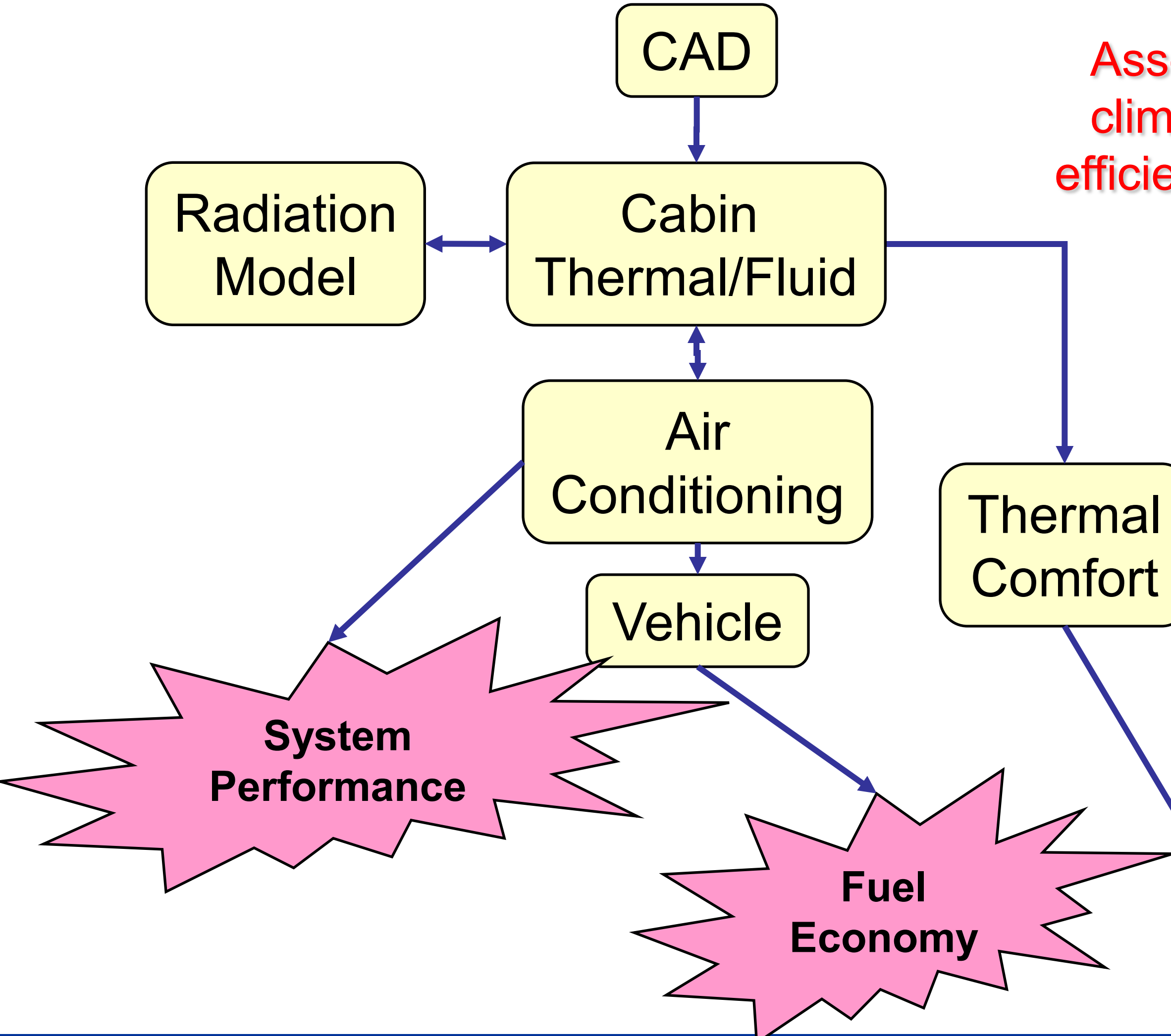
Representative Soak Temperature Data



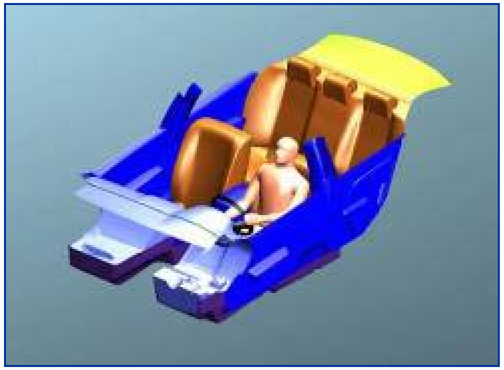
Wind Tunnel Testing



Integrating CAE Tools for Occupant Comfort

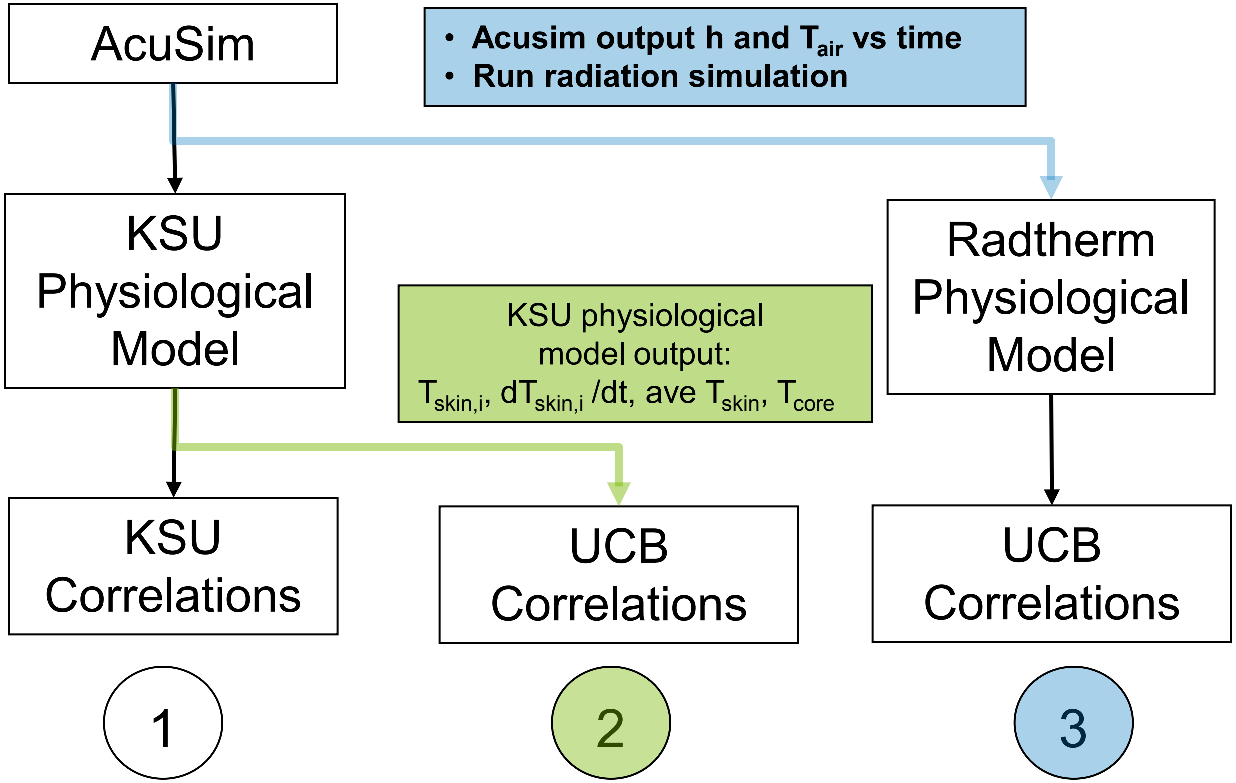


Assessing the impact of advanced climate control systems on vehicle efficiency and human thermal comfort



Evaluation of Comfort Modeling Tools

TE HVAC Vehicle Thermal Sensation/Comfort Analysis Options



Output
•Thermal sensation
•Thermal comfort

Comfort scale enables a determination of comfort / discomfort

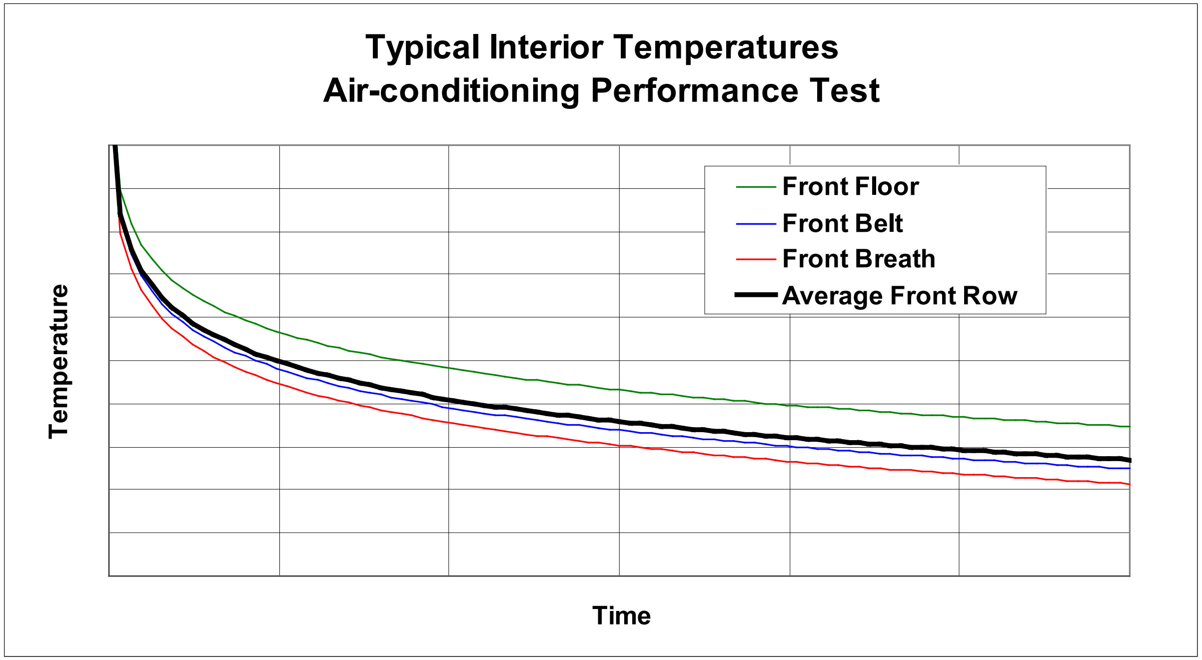
Thermal Sensation

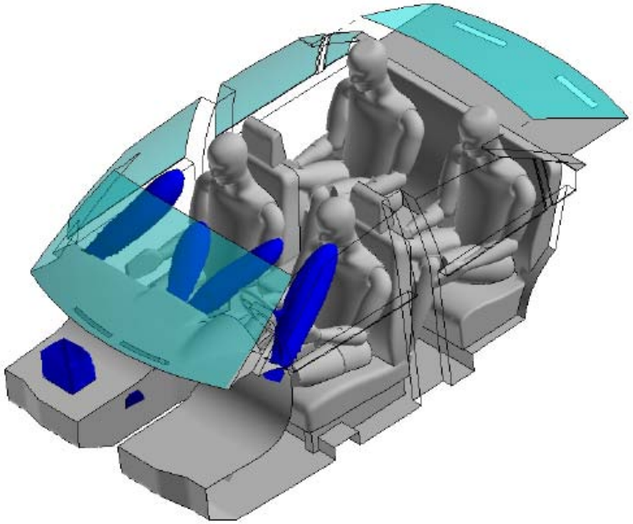
Very Cold	1
Cold	2
Cool	3
Slightly Cool	4
Neutral	5
Slightly Warm	6
Warm	7
Hot	8
Very Hot	9

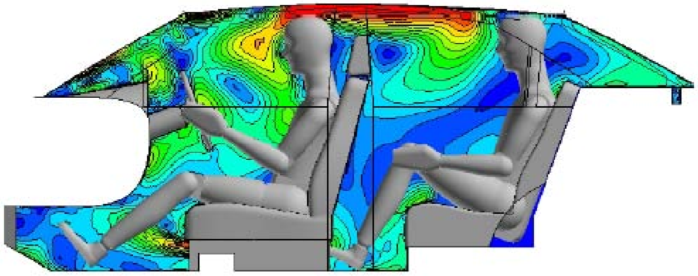
Thermal Comfort

Very Comfortable	+4
Comfortable	+2
Just Comfortable	+0
Just Uncomfortable	-0
Uncomfortable	-2
Very Uncomfortable	-4

Evaluation of Transient Interior Environment Using CFD - Computational Fluid Dynamics

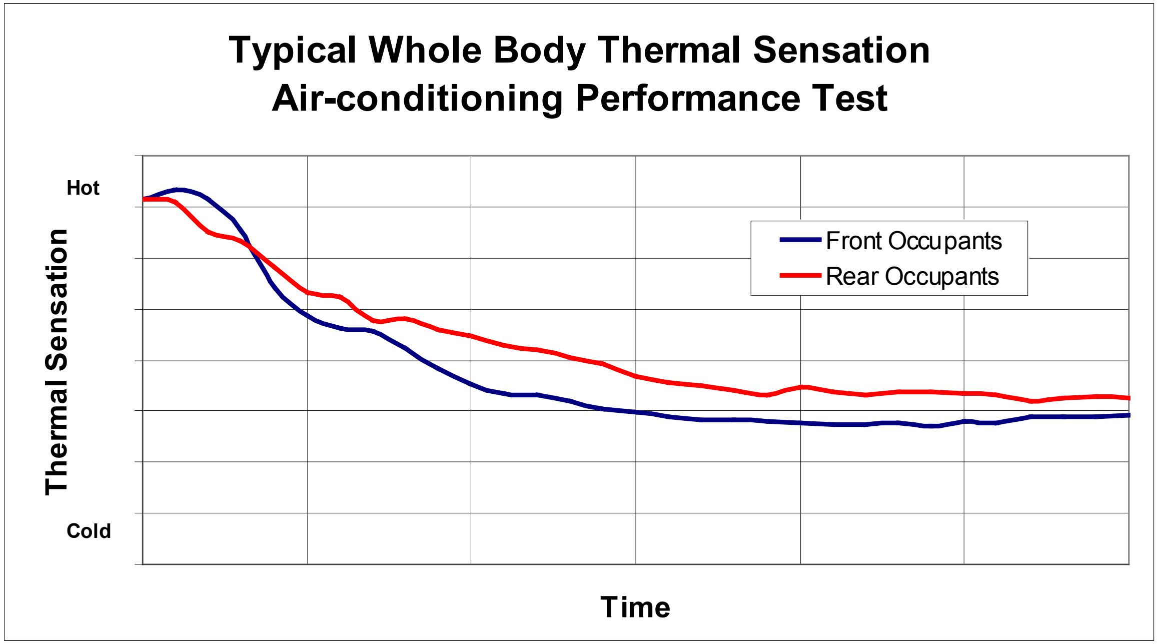






- Completed build of baseline vehicle CFD model using parametric geometry
- Began correlation of model simulations with A/C pull down and heater warm up test data
- Started building CFD model using vehicle CAD geometry

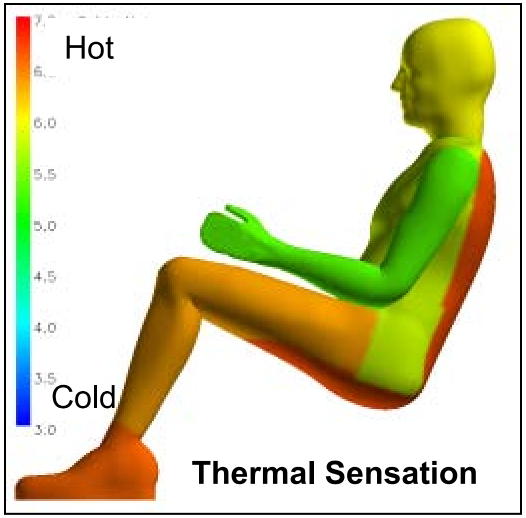
CFD Solution Data Converted into Transient Occupant Thermal Sensation Predictions



Developing correlation with wind tunnel subject tests

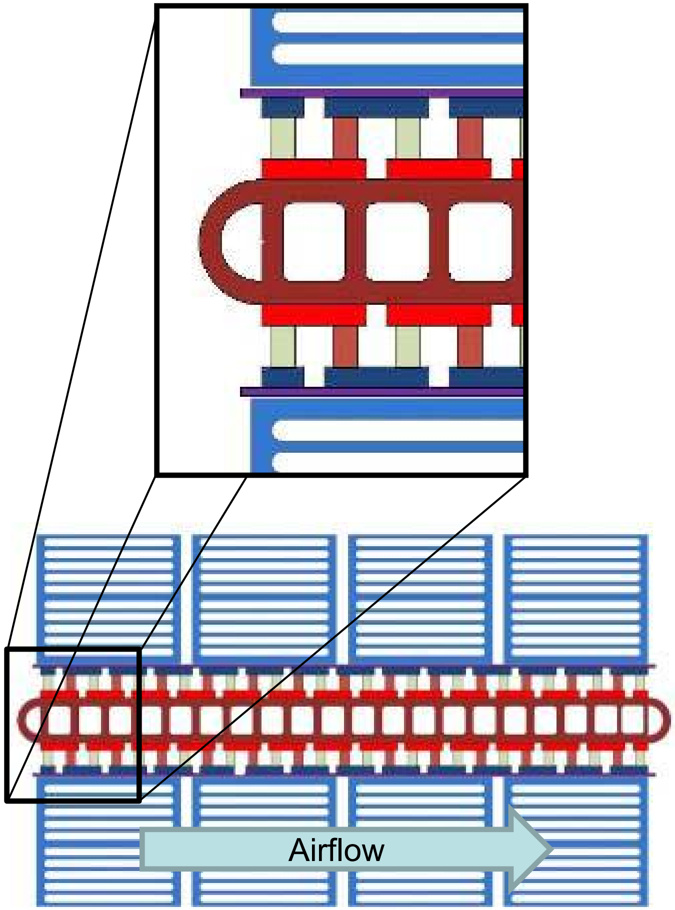
Occupant Thermal Sensation Predictions are a Function of:

- Temperature
- Velocity
- Solar Load
- Surface Radiation
- Humidity



2nd Generation TE Device Development

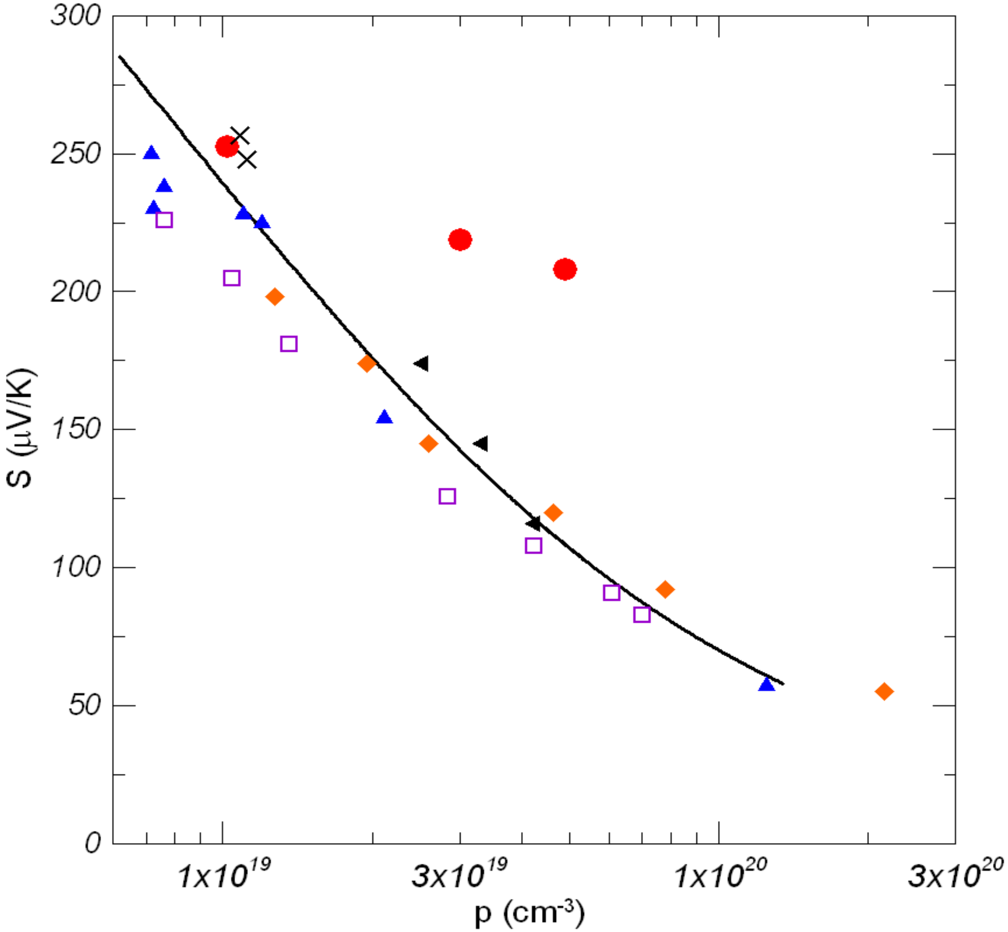
- Computer performance modeling of a modular (scalable up or down) device is ongoing.
- TE material selection has been narrowed down to 2 commercial sources and 2 TE pellet sizes for the Phase 1 prototype device.
- Preliminary electrical circuits have been established and designed with flexibility to allow the current draw to be maintained with-in acceptable limits for a range of potential system voltages.
- Initial TE engine builds have been conducted. Bonding quality studies are in progress.



Conceptual cross-section of a High Density "Liquid to Air" TE device

Thermoelectric Materials Research

- Focus on improvement in power factor to increase ZT
- Tin increases Seebeck of Bi_2Te_3 over Ge and Pb - doped material
- Tin doubles *ZT* over that of parent binary Bi_2Te_3 (ZT increases from 0.3 to 0.6)
- This effect needs to be transplanted to practical thermoelectric alloys $(Bi_{1-x}Sb_x)_2(Se_yTe_{1-y})_3$



*C.M. Jaworski, V.A. Kulbachinskii and J.P. Heremans "Tin forms a Resonant Level in Bi2Te3 that Enhances the Room Temperature Thermoelectric Power", Phys. Rev. B **80** 233201 (2009)*

Summary

- HVAC system energy consumption must be considered when developing technology for improving overall vehicle efficiency

- A Zonal TE HVAC architecture becomes more viable as vehicles evolve towards more electrification, more fuel-efficient powertrains, and occupant-based comfort criteria

- This research is a first-step towards combining these two ideas

Acknowledgements

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