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

Principle Investigator: **Clay Maranville**

Authors:

Clay Maranville, Ford Motor Company
Mike Munoz, Visteon Corporation
John Rugh, National Renewable Energy Laboratory
John LaGrandeur, BSST, LLC.
Joseph Heremans, The Ohio State University
David Marquette, Amerigon, Inc.

DOE Technology Manager: **John Fairbanks**
NETL Project Manager: **Carl Maronde**

DEER Conference
Dearborn, MI
August 5, 2009

Project Overview

Objective:

Identify a technical and business approach to accelerate the deployment of light-duty automotive TE HVAC technology, maintain occupant comfort, and improve energy efficiency.

Timeline:

Selected for award negotiation in December 2008

Expected program start is Q3 or Q4 2009

4 phase, 3 year project timeline

Major Deliverable:

Demonstration vehicle delivered at end of phase 4

Project Partners

Project Lead
Vehicle-Level Systems Design & Analysis

Thermal Comfort Modeling
Advanced Test Methods

HVAC System Design,
Analysis, & Integration
Thermal Comfort Modeling

TE System Research,
Design, and Integration

Thermoelectric Materials Research

Climate Controlled Seat Technology

DOE Project Targets

- Accelerate development of TE heat-pump modules and systems
- Augment or replace need for A/C Compressor and PTC-based heating
- Improve fuel economy and associated GHG emissions vs current production HVAC technology
- System Coefficient-of-Performance Targets:
  - COP > 1.3 for cooling
  - COP > 2.3 for heating
- Reduce power consumption of A/C compressor by >33%
- Target commercial introduction between 2012 – 2015
- Develop and test a distributed TE HVAC vehicle system
- Deliver a demonstration vehicle to DOE for further independent verification of system performance and efficiency for 1 – 5 occupants

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

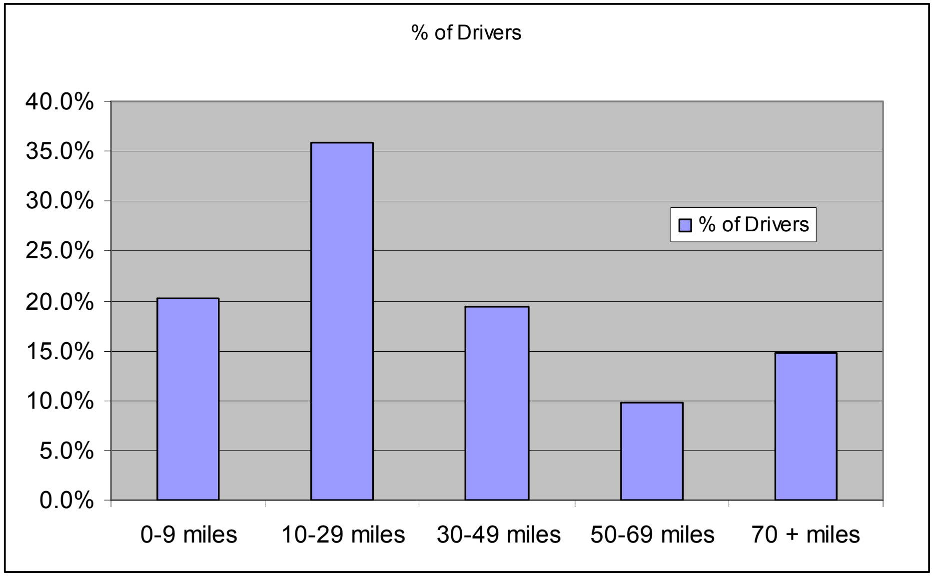
Success Criteria

- 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

Trends in Vehicle Drive Patterns

- 6 daily vehicle trips per household
- 58 daily vehicle miles per household
- 9.9 miles per trip average
- Average annual miles:
  - 13,785 for all drivers
    - 16,920 for men
    - 10,233 for women
- Average commute:
  - 12.11 miles
  - 23.32 minutes
  - 32.23 miles per hour

Total Daily Travel



Vehicle drive patterns help to determine the design of HVAC systems

Data compiled from 2001 NHTS transportation study

Vehicle Occupant Thermal Comfort

Cabin environmental conditions

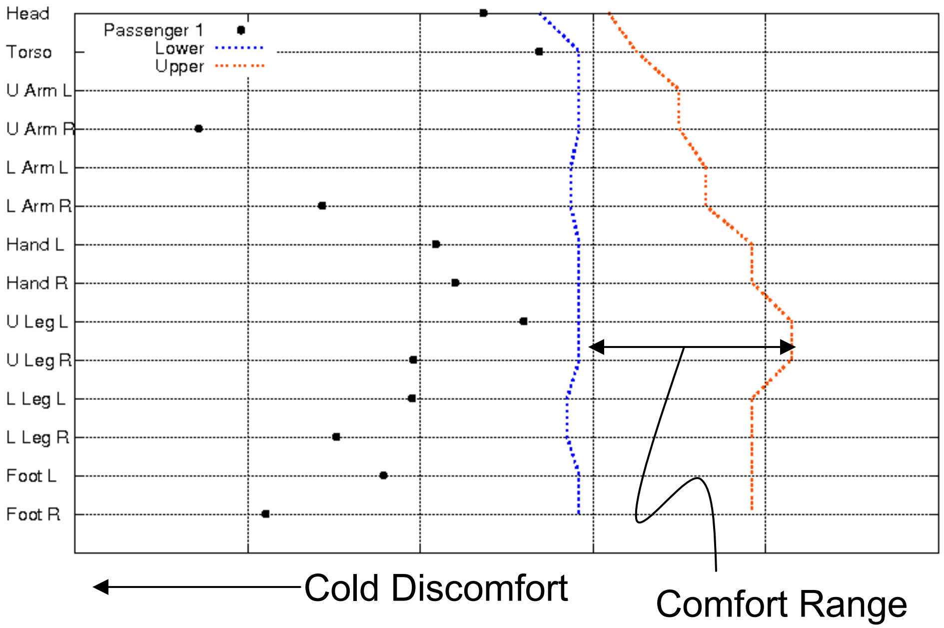
- Occupant physiological response
- Occupant perception of comfort

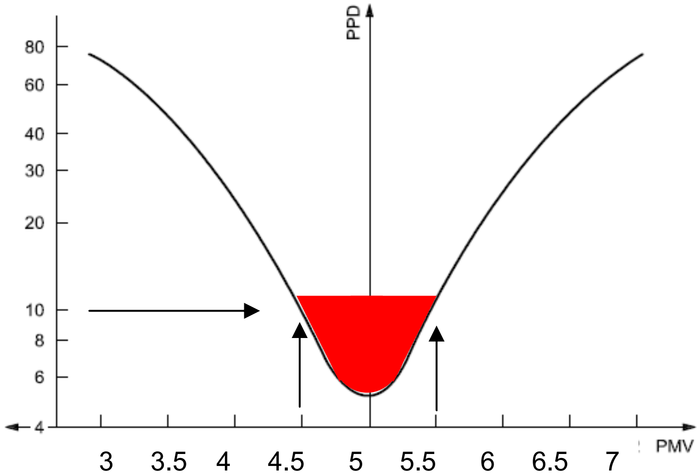
Parameters Defining Comfort

- Activity (Metabolic Rate)
- Clothing (Insulation)
- Air Temperature
- Air Humidity
- Air Velocity
- Mean Radiant Temperature
- T_{eq} Asymmetry
- Transient Physiological (Metabolic) & Psychological Responses

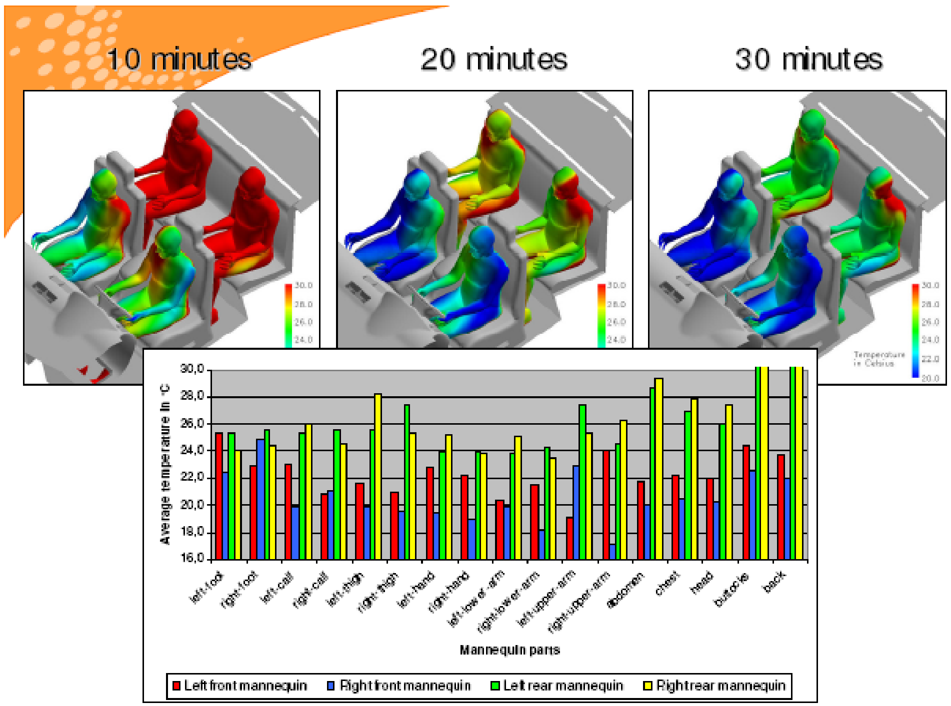
Results of Parameter Input

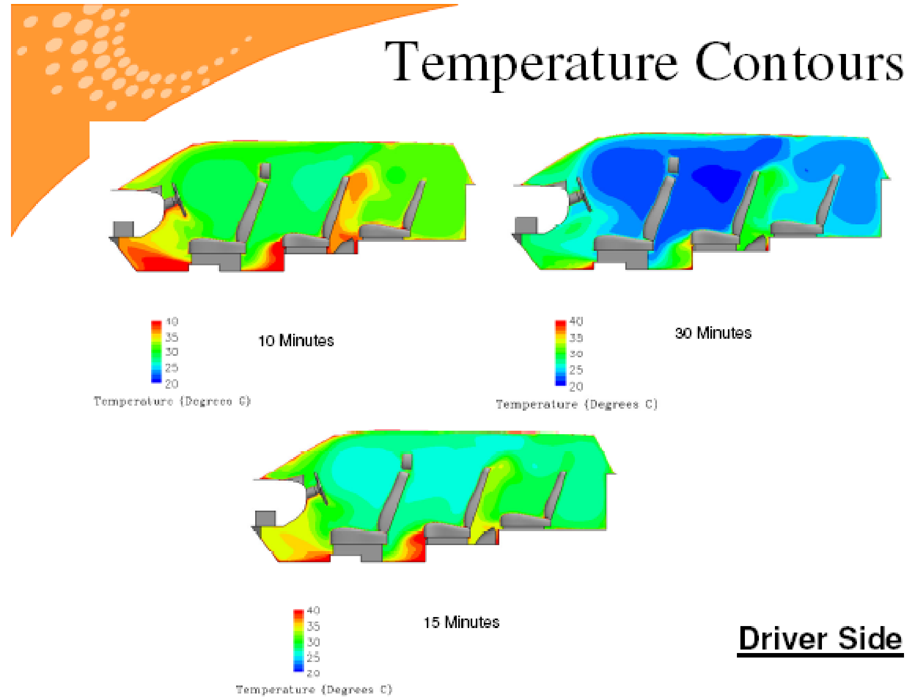
- Equivalent Temperature (T_{eq})
- Predicted Mean Vote (PMV)
  - 9-point thermal sensation scale
- Percent Persons Dissatisfied (PPD)
  - Acceptable level: 10%? 5%?





CAE Tools to Assess Vehicle Environment

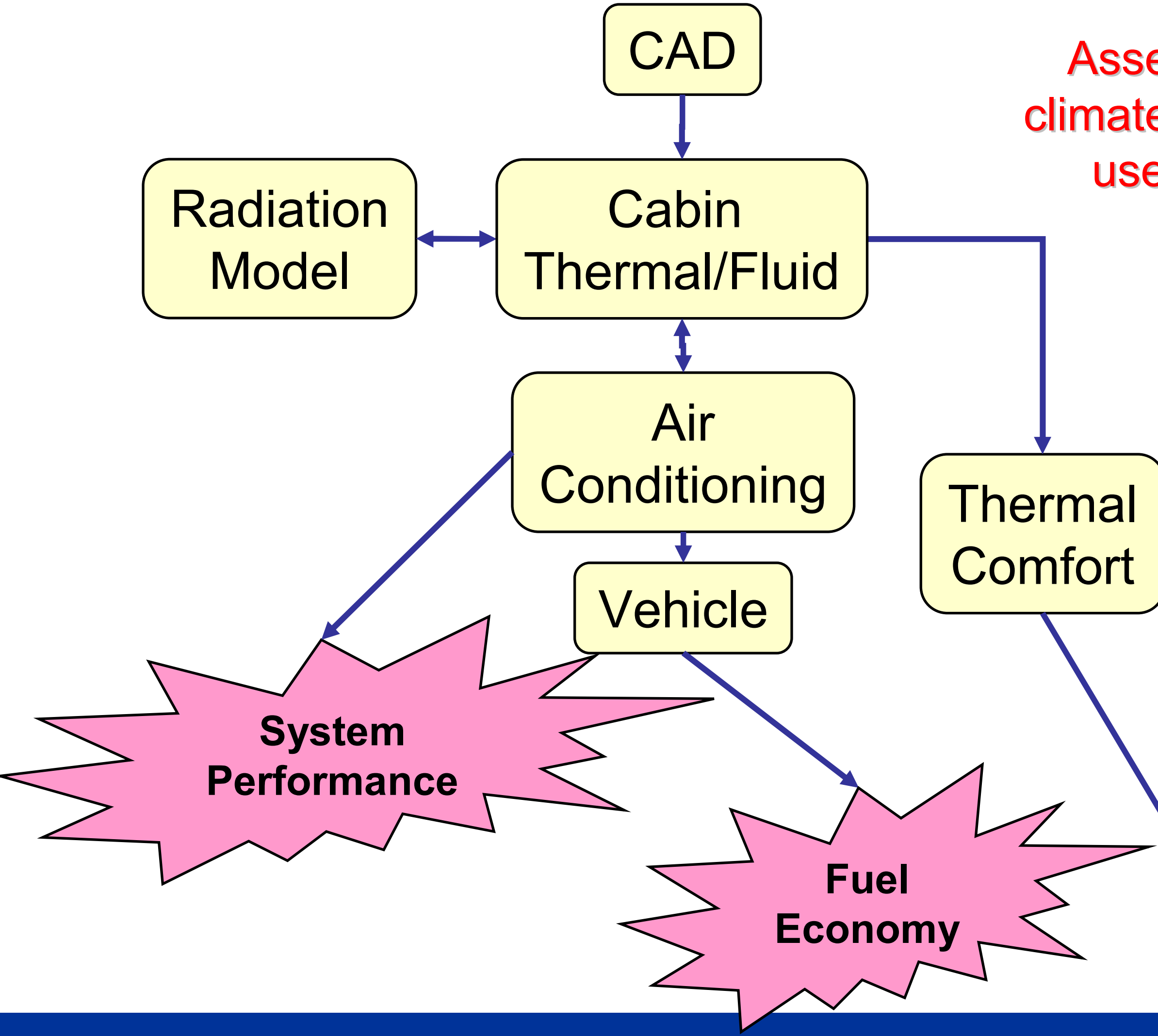




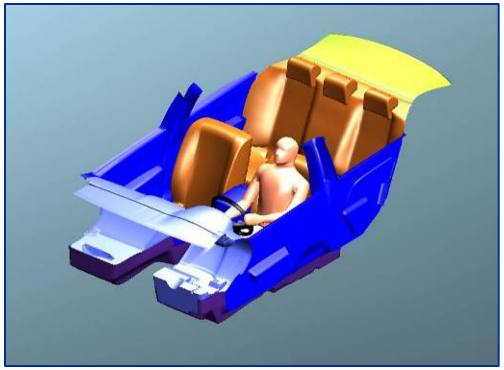
- CAE toolset capable of predicting transient heating or cooling simulation
- Occupant comfort analysis based on Kansas State model

Courtesy of Mike Munoz, Visteon Corp.

Integrating CAE Tools for Occupant Comfort

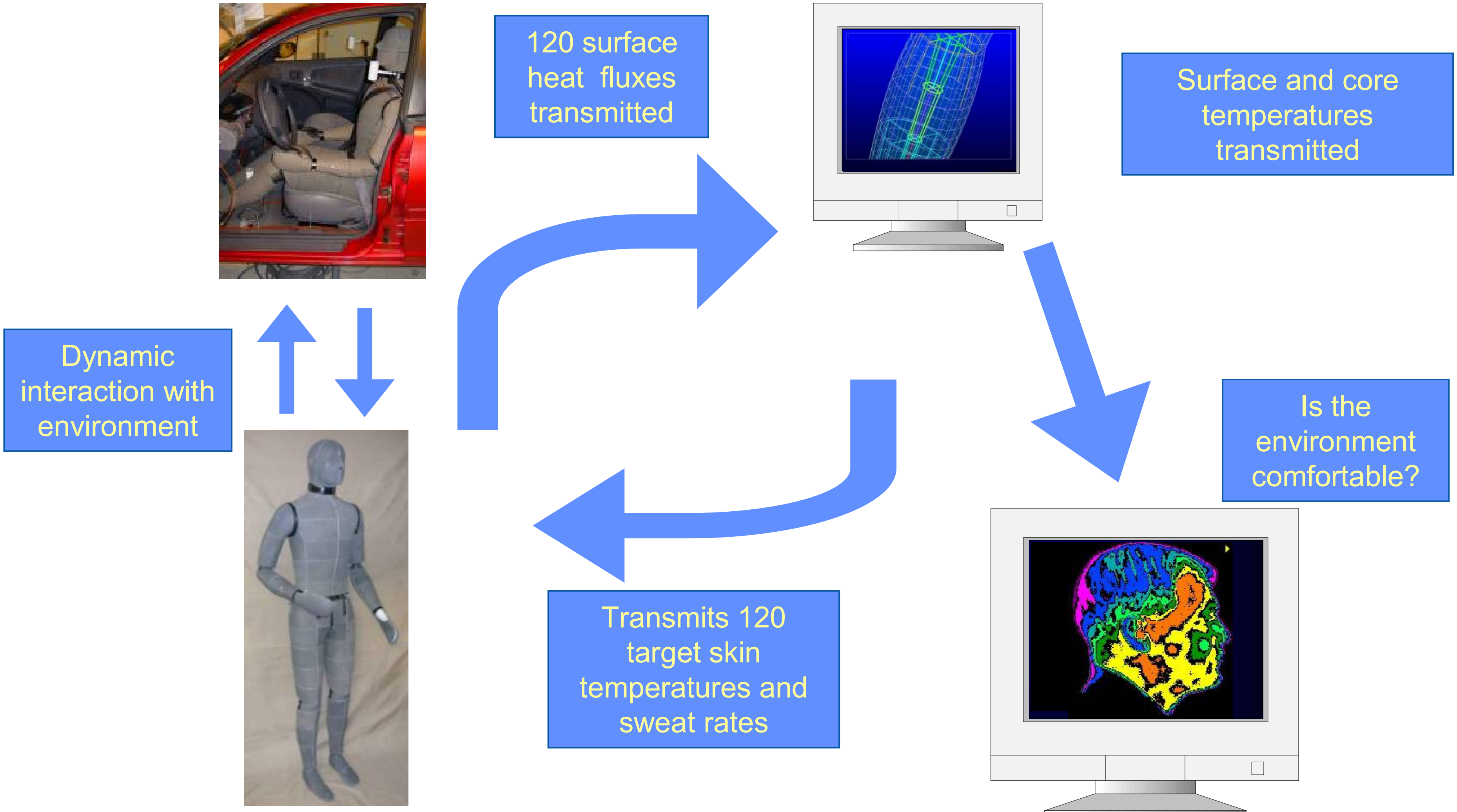


Assessing the impact of advanced climate control systems on vehicle fuel use and human thermal comfort

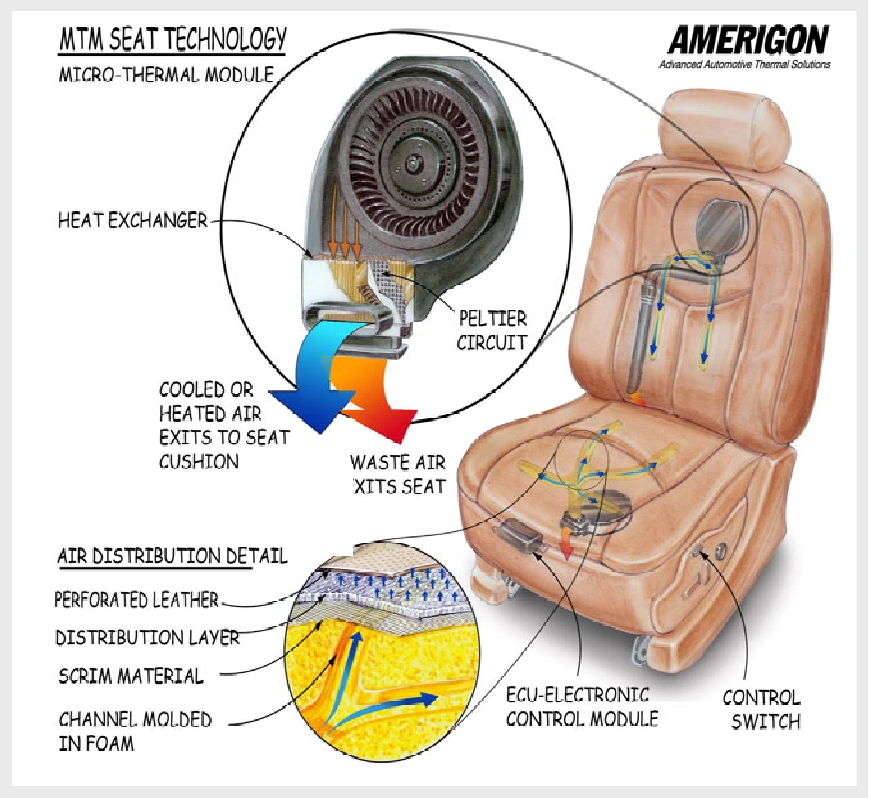


Courtesy of John Rugh, NREL

Linking the Tools Together



Integrating TE HVAC Technology into Vehicles

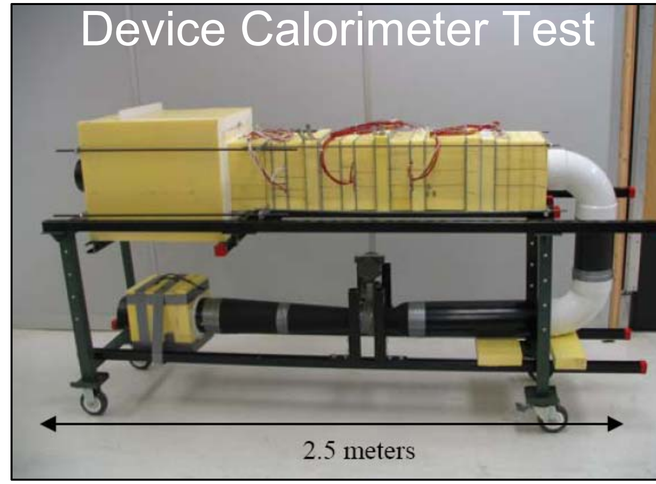


- Advanced climate-controlled seats will be used as a node for the TE HVAC distributed system

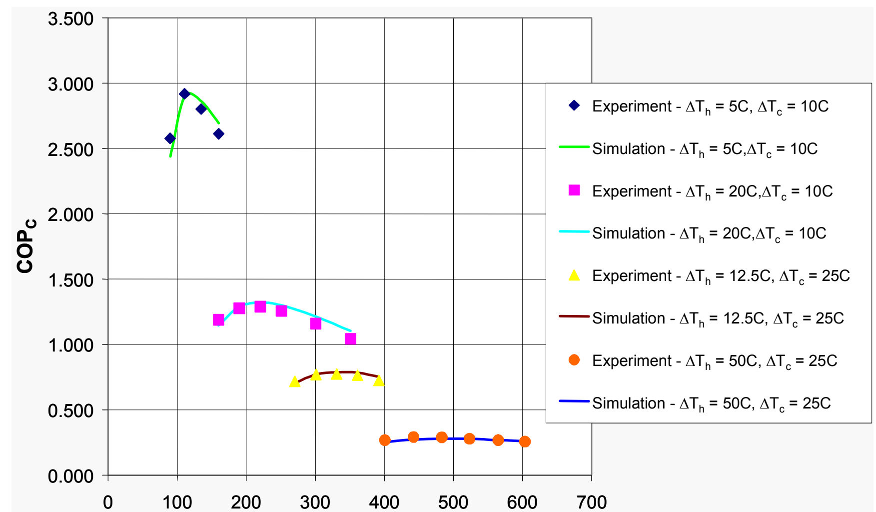
Courtesy of Dave Marquette, Amerigon

Preliminary TE Device Design & Modeling

Prototype TE HVAC Module



Heating Mode		Cooling Mode	
Q_h (W)	450	Q_h (W)	300
Qin (W)	200	Qin (W)	200
COP	2.5	COP	1.5
Airflow, liters/sec	18.9	Airflow, liters/sec	12.6
Water flow rate, cc/s	60	Water flow rate, cc/s	60
ΔT air, ^{0}C	20	ΔT air, ^{0}C	-15^{0}C
T inlet air, ^{0}C	22^{0}C	T inlet air, ^{0}C	22^{0}C
T inlet water, ^{0}C	22^{0}C	T inlet water, ^{0}C	22^{0}C



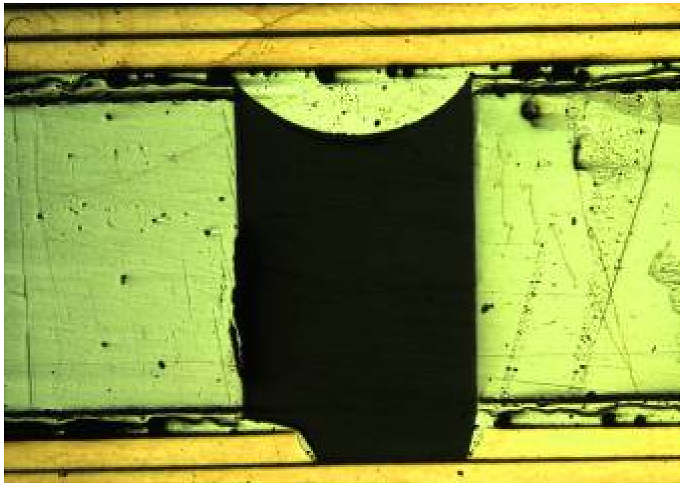
Courtesy of John LaGrandeur, BSST

Advanced TE Materials Research

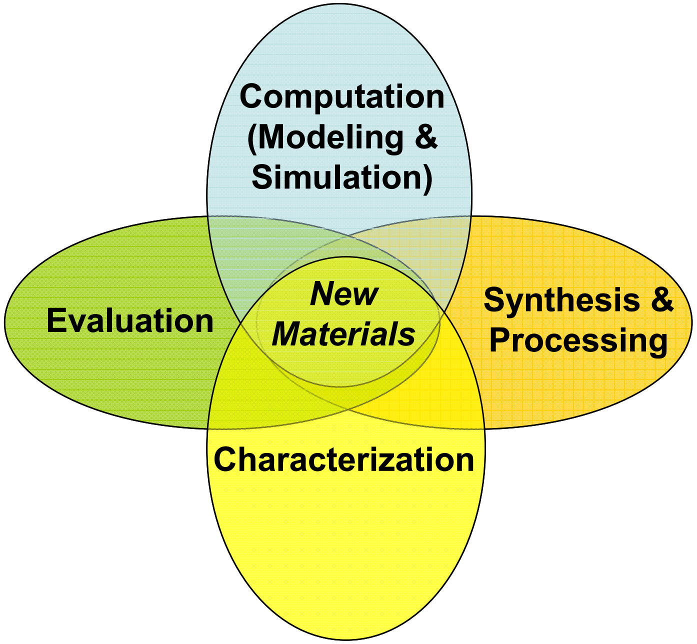
Thermoelectric Heat Pumps are Complex Engineered Devices

Maximize ZT
Minimize material usage

Reduce Interface Resistance

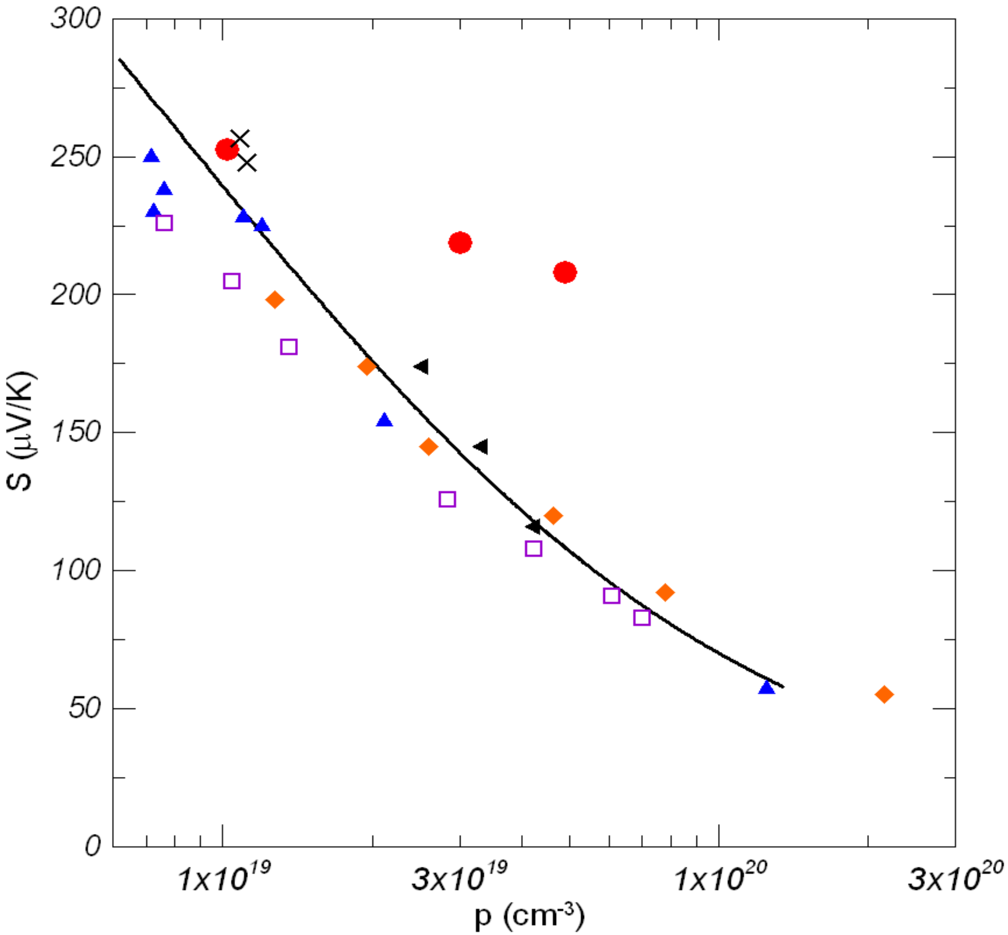


Optimize design of p-n couple



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 $(Bi_{1-x}Sb_x)_2(Se_yTe_{1-y})_3$



Jaworski, Kulbachinskii and Heremans, Phys. Rev. B (submitted)

Courtesy of Joseph Heremans, OSU

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

- We look forward to beginning this exciting project in the near future.
- Thanks to the Department of Energy for their partnership support of this project. In particular, John Fairbanks at DOE-EERE and Carl Maronde at NETL.
- Thanks to the technical teams at Ford, Visteon, BSST, Amerigon, NREL, and OSU.

Thank You!