Improving efficiency of a vehicle HVAC system with comfort modeling, zonal design, and thermoelectric devices

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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

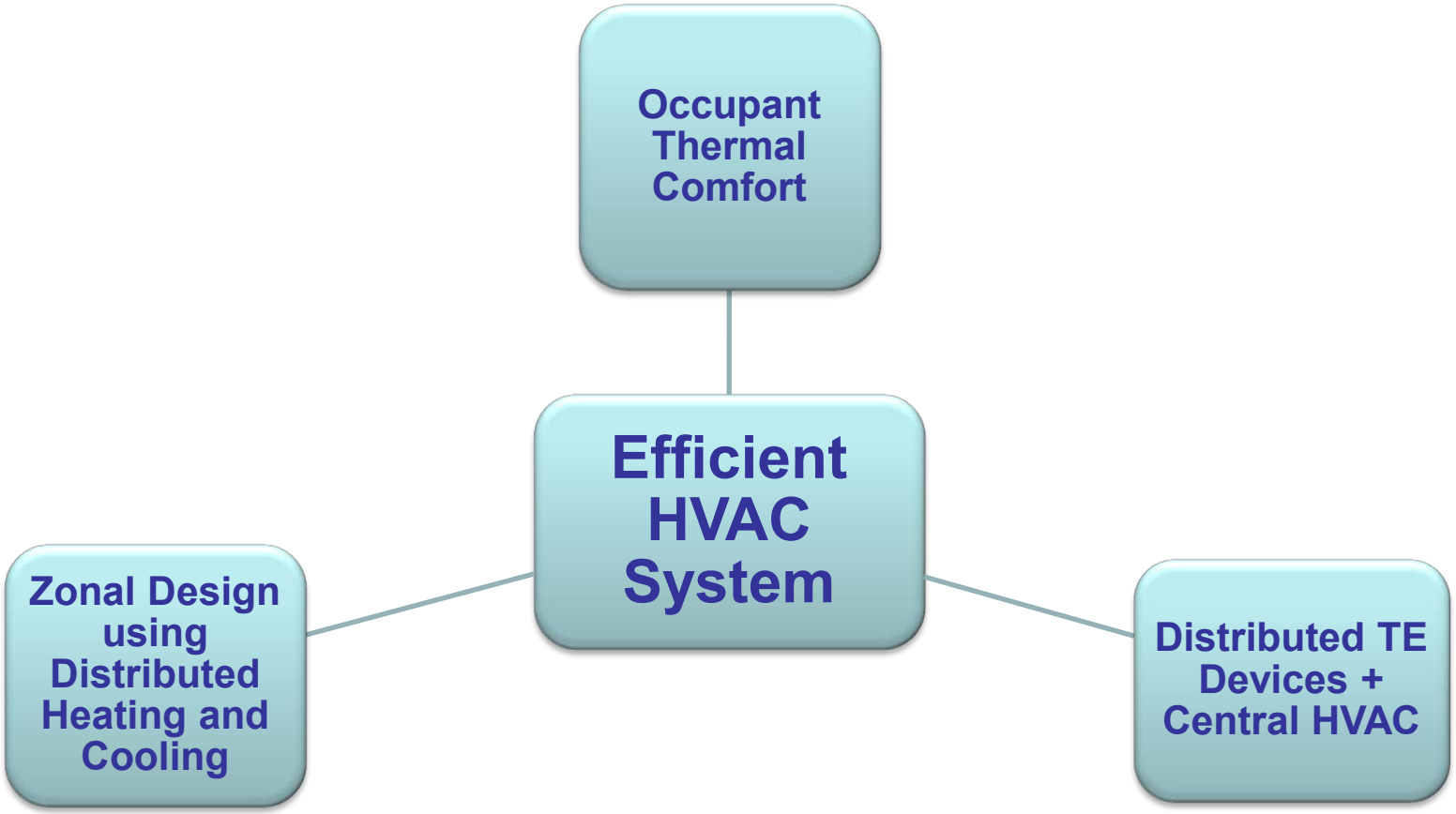
Program Objectives:

- 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

FY2012 Objectives:

- Continue thermal comfort modeling toolset development
- Finalize design & build all components for prototype vehicle integration
- Complete TE device fabrication and bench testing
- Complete evaluation of advanced TE heating/cooling materials at module level
- Initiate ancillary loads trade-study
- Conduct initial system and component cost analysis

Technical Approach to HVAC Design



Phase 3 Task Overview (Jan '12 to Nov '12)

System-level HVAC architecture design

- Complete component packaging study
- Enhance multi-domain thermal comfort tools for design optimization
- Detailed design, build, and bench validation of components and subsystems:
  - Power supplies, air handling & distribution, liquid system, sensors & controls
- Initiate ancillary load reduction trade-off study
- Complete detailed system BOM and cost analysis

TE HVAC device development and materials research

- Utilize predictive computer models to optimize thermoelectric engines and matching heat exchangers
- Design and develop high performance mass producible liquid and air heat exchangers
- Continue to develop and optimize the manufacturing methods for fabricating thermoelectric engines
- Investigate routes to advanced thermoelectric materials with enhanced figure-of-merit

Success Criteria

- Vehicle-intent TE based subsystems meet bench-level performance and durability tests
- Cost analyses shows that there is a potential business case for a TE HVAC system

Phase 4 Workplan (Dec'12 to Aug'13)

System-level HVAC architecture design

- Integrate zonal climate system components, instrumentation, and sensors into vehicle
- Deploy basic control strategy for zonal, occupant-based HVAC system control
- Validate zonal system performance and compare to baseline tests
- Conduct jury testing to assess thermal comfort of zonal system
- Calculate HVAC energy utilization and compare to baseline tests

TE HVAC device development and materials research

- Study conducted to assess the design and manufacturing routes to low-cost, high-performance TE subassemblies
- Complete a vehicle-level commercialization assessment for zonal TE HVAC deployment

Success Criteria

- TE HVAC system meets thermal comfort performance criteria
- TE HVAC system demonstrates reduction in energy consumption compared to baseline
- Measured TE device COP meets program objectives
- Cost study and commercialization analysis show TE HVAC commercialization pathway

Vehicle Platform: 2011 Lincoln MKZ HEV

Occupant Thermal Comfort Analysis

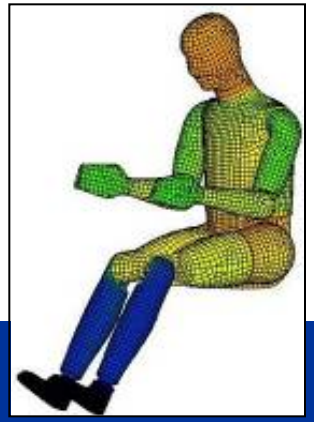
Thermal manikin compared to trained climate control observer
Temperature, sensation, comfort

Design impacts performance
Design for comfort

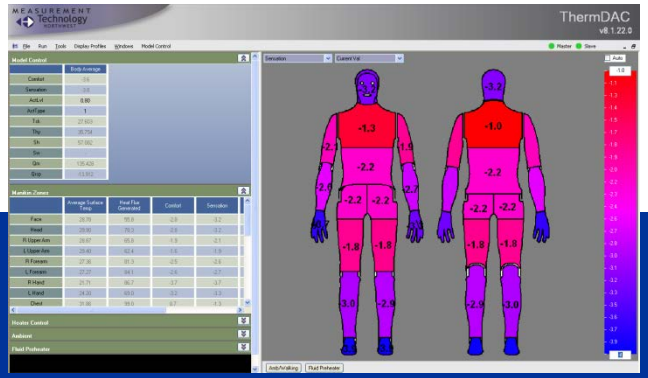
Thermal Comfort

Thermal Sensation

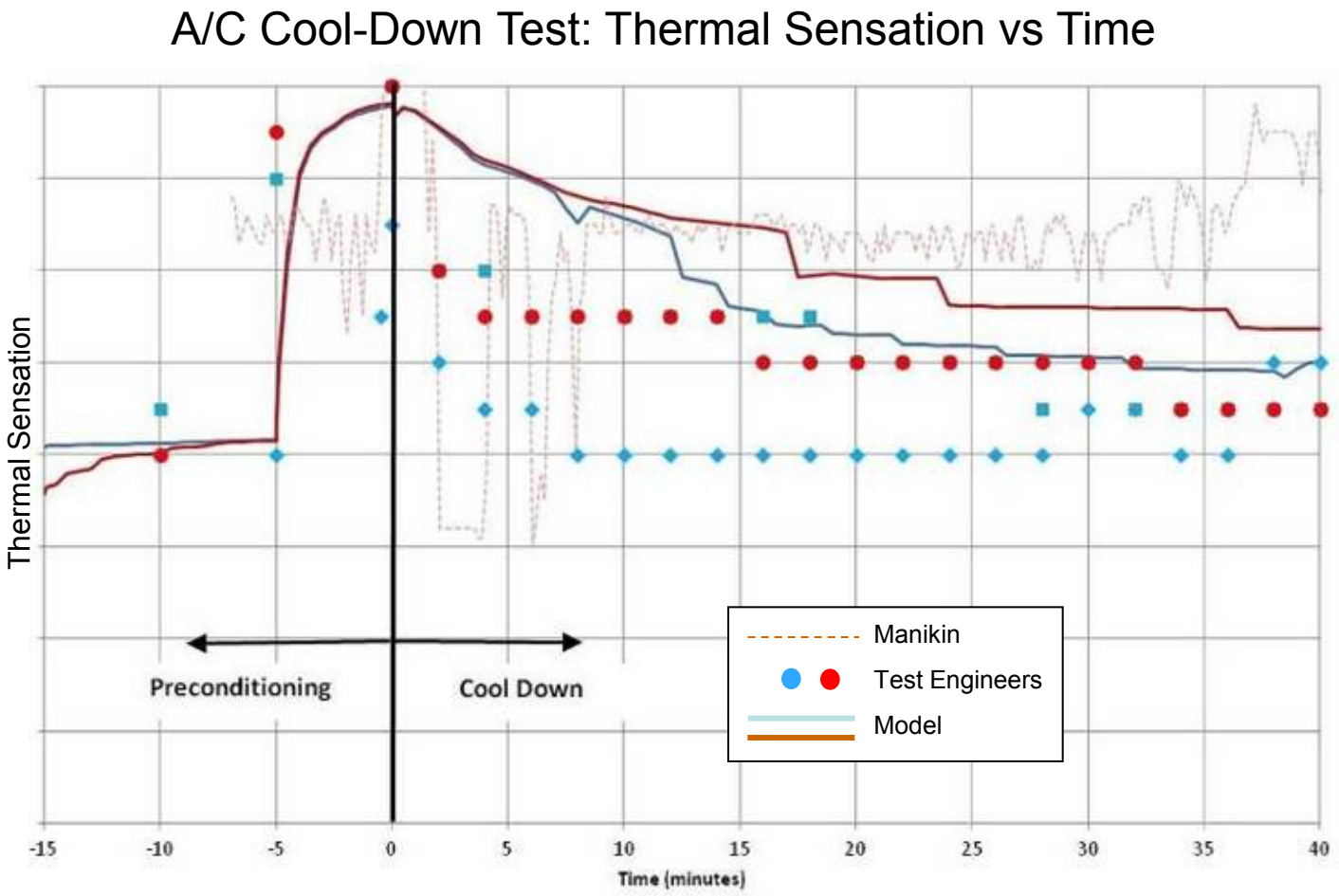
Thermal manikin helps to validate virtual manikin
Segment temperature, sensation, comfort



CAE tool guides design
Zonal climate control



Comfort Validation Study



Good correlation between models, manikin, and test subjects

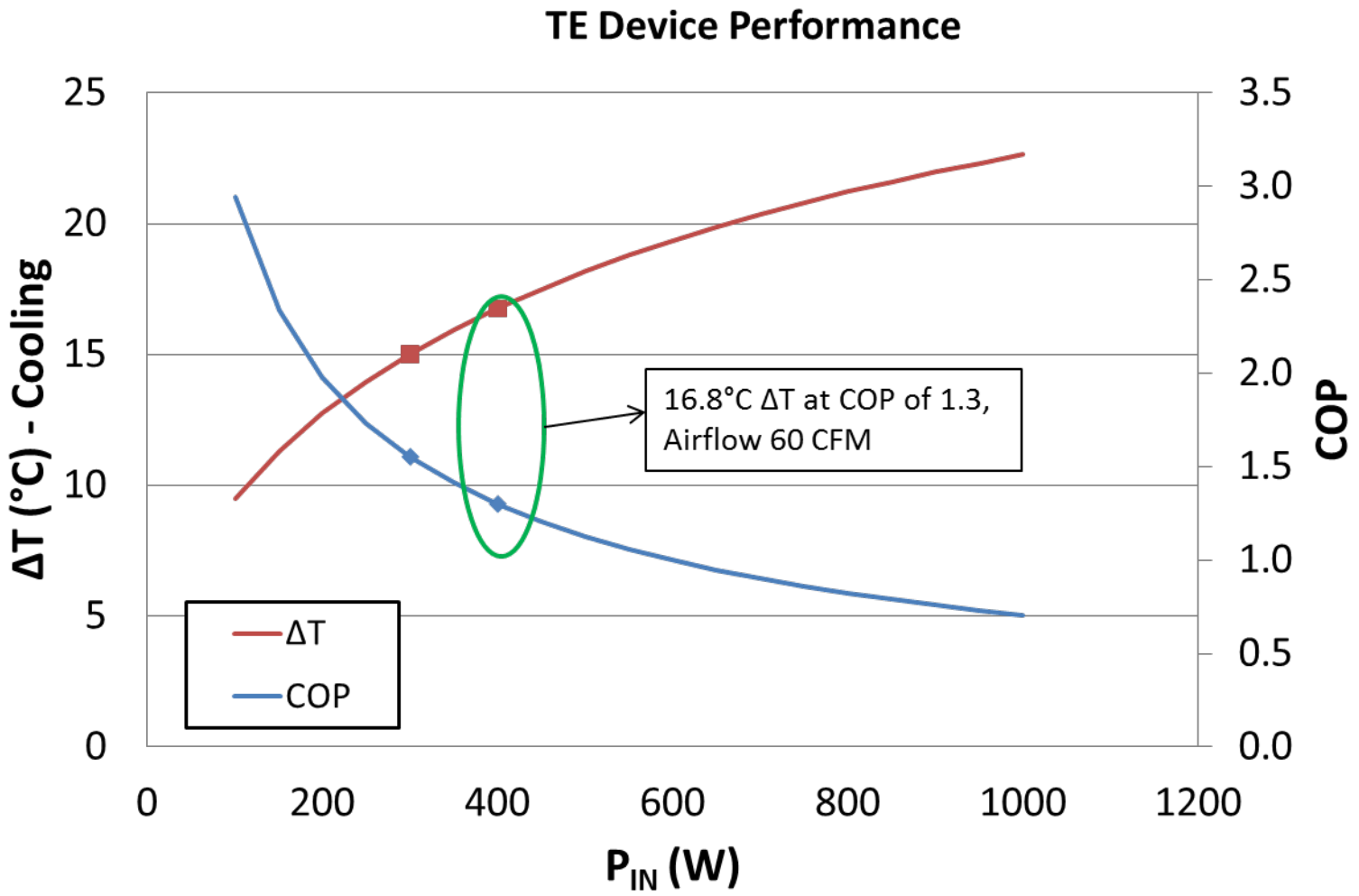
ZONAL THERMOELECTRIC DEVICE DEVELOPMENT

TE Device for Zonal System
LWH: 50x120x300mm

TE unit bench test

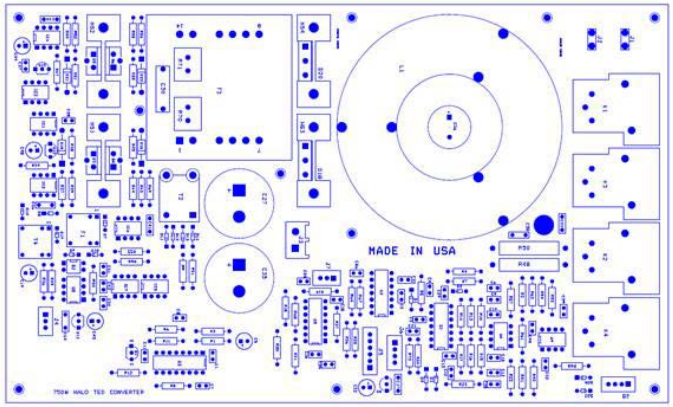
- Thermal cycling testing is ongoing for 2 units, currently at ~7000 cycles each with an average input power of ~800W
- Sealed units capable of managing condensation
- Transient model validation and correlation completed
- 6 Units for system testing and the vehicle build have been fabricated

TE DEVICE PERFORMANCE MODEL VS TEST

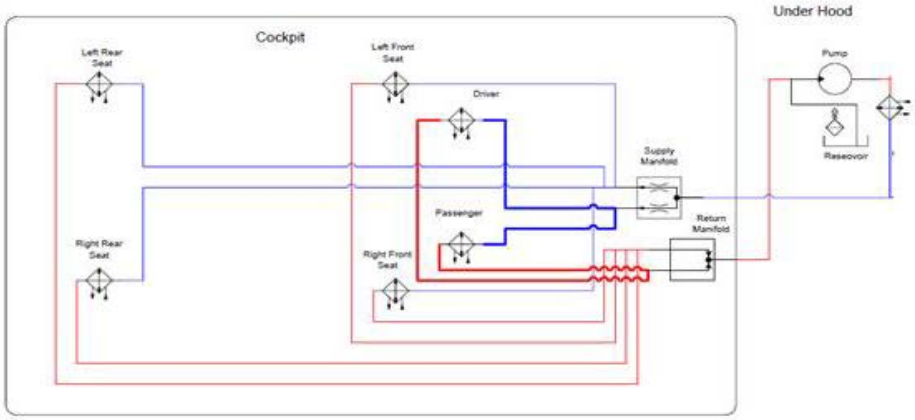


Zonal HVAC System Design

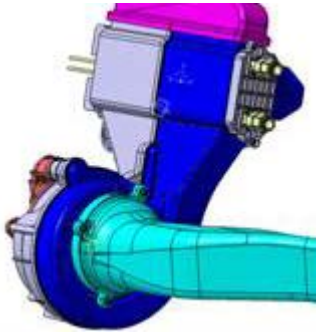
- Design verified using subjective and objection evaluations in thermal chamber tests
- HVAC design requirements developed to allow detailed component and sub-system design:
  1. Power Supplies for TE units, Blowers, and Liquid Pumps
  2. Liquid Loop
  3. Air Handling, Including Ducts & Blowers
- System and component fabrication completed
- Verification bench testing scheduled for 4Q2012



TE Power Supply PWB Design

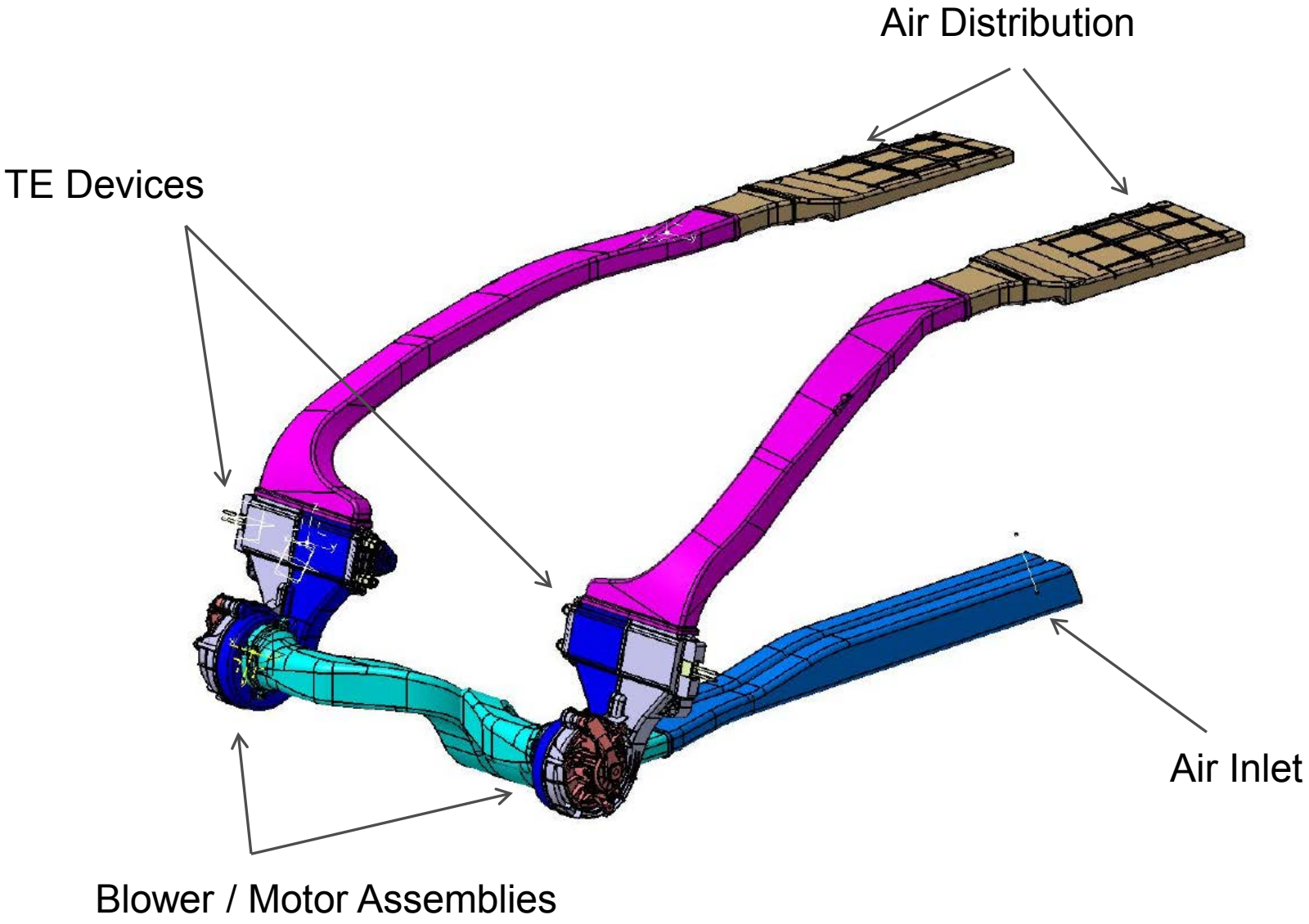


Liquid Loop Schematic

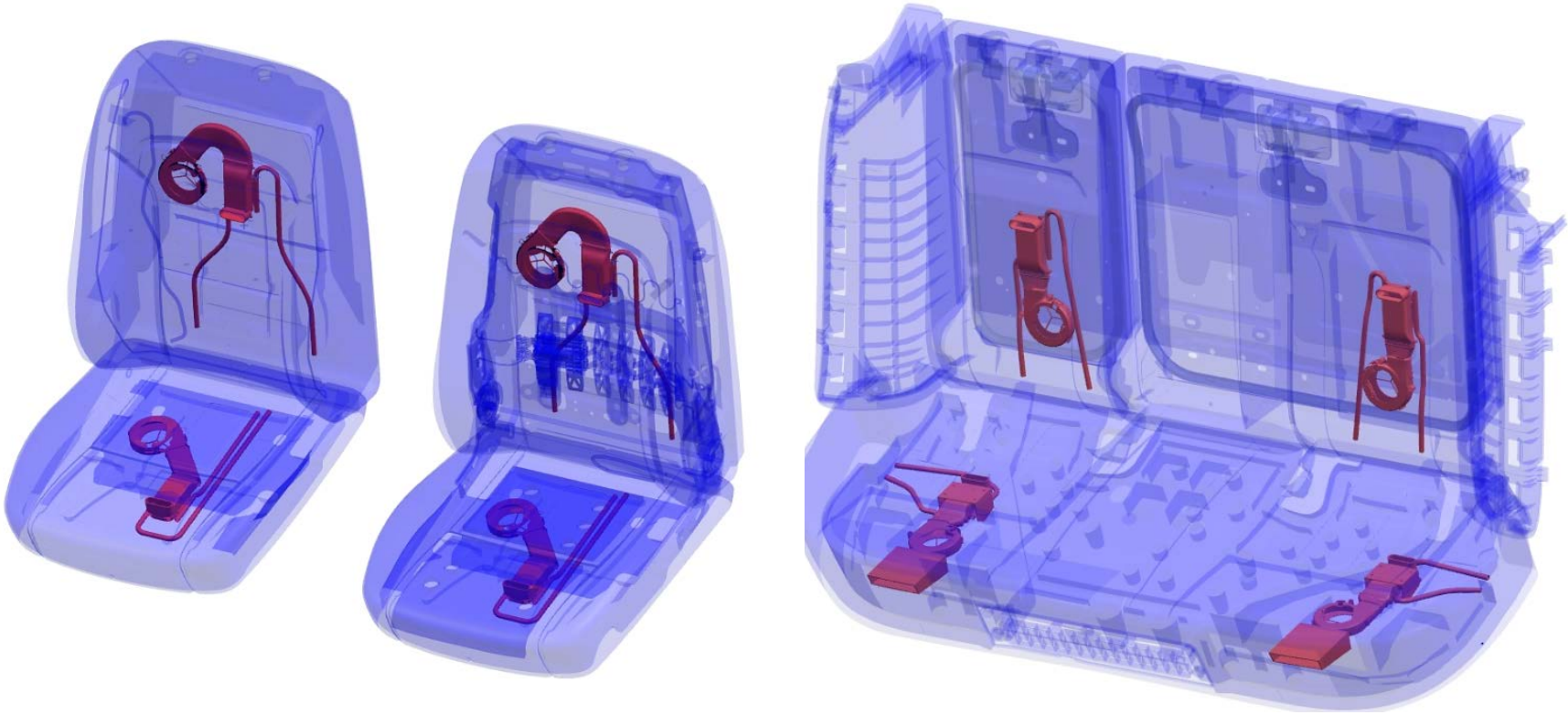


Blower & TE Housing Design

Zonal System Layout



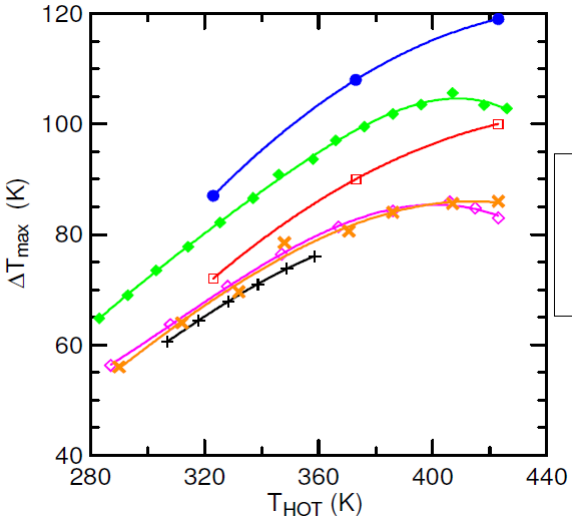
CLIMATE CONTROL SEAT DEVELOPMENT

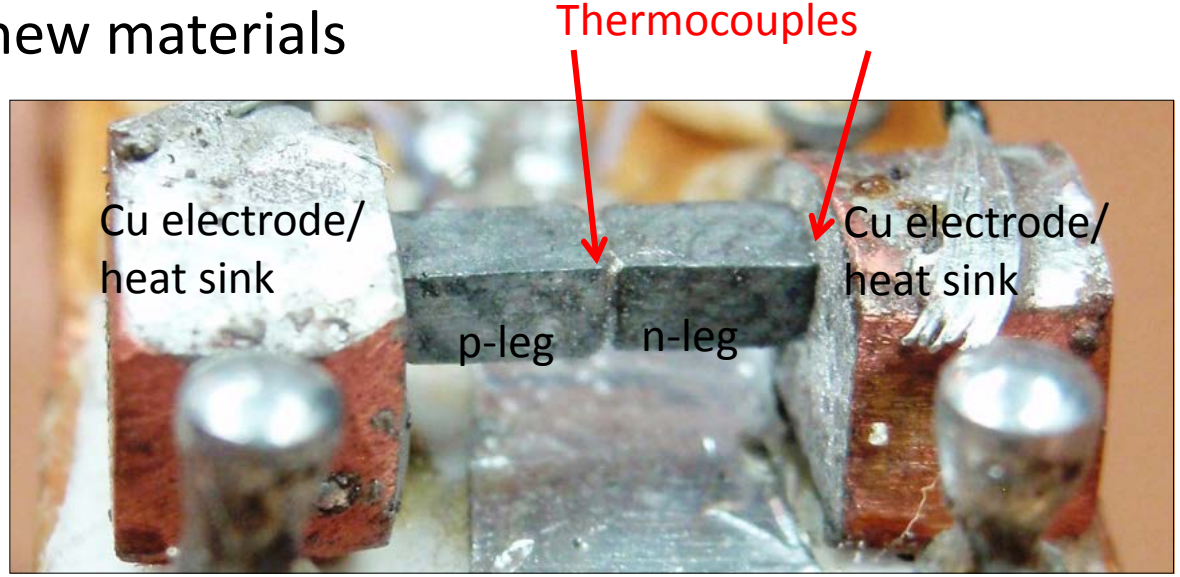


- Design of Liquid Loop CCS completed
- 8 liquid/air TE units in 4 seating positions
- Units capable of 10°C DT at 100 W_{elec}
- Utilize similar air distribution methodology as current CCS designs

Advanced Materials: Peltier couple tests

- Pass current *(I)* through assembled *p-n* Peltier couple
  - Measure $\Delta T(I)$, some *I* yields ΔT_{max}
  - Direct measurement of device *ZT*
- zT_{device} tests on OSU material do not match up with 3 parameter zT
  - Attempting different contact technologies to verify performance of new materials





Summary and Future Work

- Project focuses on developing methods to optimize climate system efficiency while maintaining occupant comfort at current levels using new technology, architecture, and controls approaches
- Zonal TE HVAC commercial viability improves as vehicles evolve towards higher levels of electrification and engineering attribute criteria accounts for quantitative occupant-based comfort metrics
- Project on target to meet Phase 3 milestones and deliverables by the end of 4Q12:
  - Architecture selection, detailed design, fabrication, and bench validation testing
  - TE device performance and durability assessment
  - Cost analysis
- In-vehicle installation planned for 1Q13, system validation testing May – July 2013, project completion targeted for August 2013

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